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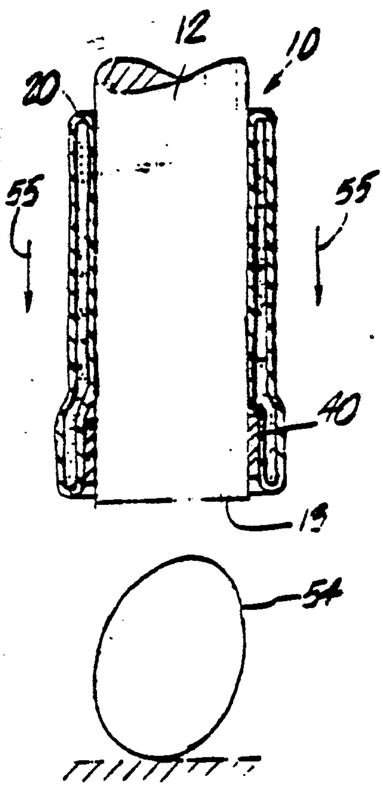
(57) Abstract

A manipulator (10) for grasping an article (54) comprises an elongate arm (12) having a forward portion (13) and a grasping means (20) on the arm (12), typically on the exterior of the arm (12). The grasping means (20) comprises an inner wall section (32) and an outer wall section (34) each comprised of flexible material with an annular region therebetween. The wall sections (32 and 34) form at least a portion of a continuous, closed, double-wall structure. The inner (32) and outer (34) wall sections are capable of relative axial movement. The grasping means (20) is capable of being axially revolved on the extension of the arm (12) so that a portion of the grasping means (20) extends beyond the forward portion (13) of the arm (12) for grasping an article (54). Preferably the grasping means (20) is permanently attached (40) to the arm (12) so that when the grasping means (20) is revolved on the forward portion (13) of the arm (12) and grasps an article (54), it cannot be revolved off of the arm (12).



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MANIPULATOR

There is a need for systems for remotely grasping articles, and particularly fragile articles and articles having irregular shapes. For example, robotic manipulators have difficulty in grasping fragile articles. Complex control systems are required to prevent exertion of excessive pressure on the article; excessive pressure can result in damage to a fragile article. Precise control of the art of a robotic manipulator is required because manipulators usually must precisely grab an object; any offset from the center of an object can result in a missed object. Moreover, a robotic manipulator can require a different "hand" for each different shape article to be grasped.

Another example of the difficulties involved in grasping remote articles is evidenced by the frustration experienced when attempting to insert a small fastener such as a small screw into a substrate. The screw is difficult to hold and the screw driver often tends to slip away from the screw head. Further, if the screw is to be placed into an inaccessible location such as a narrow recess, the difficulty of holding the screw is compounded. A similar problem is experienced when trying to remove a screw from a substrate. Once the screw is completely unthreaded, usually it falls off the tip of the screw driver, and often is lost, particularly when working with mechanical equipment.

Other articles which can require remote grasping include fruit on a tree, underwater objects such as objects on the ocean floor, radioactive articles such as a radioactive pellets used in cancer therapy, dangerous animals, and light bulbs.

The present invention satisfies the need for a system for remotely grasping articles, and is particularly suitable for fragile articles and articles having an irregular exterior. A system according to the present invention has a manipulator that comprises an elongate arm having a forward portion and grasping means on the arm, typically on the exterior of the arm. The grasping means, (also referred to as a grabber, grasper, and holding means), can revolve along the longitudinal axis of the arm, and extend beyond the forward portion of the arm for grasping an article. The grasping means comprises an inner wall section and an outer wall section, both comprises of flexible material. The wall sections form at least a portion of a continuous, closed, double-wall structure having an annular region therebetween. The annular region can have friction reducing means such as a lubricant therein. The inner and outer wall sections are capable of relative axial movement so that the grasping means is capable of being axially revolved on the arm and onto the article to be grasped.

Also, typically the unstressed inner circumference of the inner wall section of the grasping means is sufficiently less than the outer circumference of the arm that both wall sections of the grasping means exert a force toward the arm normal to the surface of the arm.

Preferably the manipulator includes means for permanently attaching a portion of the grasping means to the arm so that when the grasping means is revolved beyond the forward portion of the arm and grasps an article, it cannot be completely revolved off of the arm. The attaching means can be an adhesive between the grasping means and the arm.

To use the manipulator, the forward portion of the arm is placed near the article to be grasped. Then an axial force is applied onto one of the wall sections of the grasping means toward the article while the other wall section of the grasping means is restrained from axial motion in that direction. This axially revolves the grasping means along the arm and beyond the forward portion of the arm and onto the article, whereby the article is grasped by the grasping means.

It is easy to release a grasped article with the manipulator of this invention. To release the article, all that is required is to axially revolve the grasping means along the arm away from the forward portion of the arm. Thus if the manipulator is used to pick a piece of fruit from a tree, the fruit can easily be deposited in a basket.

Activating means such as an elongated rod can be provided for remotely revolving the grasping means for remotely grasping and releasing an article.

In one version of the invention the arm is hollow and sufficiently large that once the article is grasped by the grasping means, the grasping means can be axially revolved onto the arm such that the article is deposited inside the arm.

In another version of the invention, the grasping means can be provided with means to facilitate gripping of an article. For example, the walls of the grasping means can have ridges or projections or fingers; a surface-absorbent material especially for collecting fluids; and/or a tacky adhesive. The wall can also be roughened or pitted.

In one version of the invention the grasping means is equipped with a valve for inflating the space between the inner and outer walls to exert more pressure on the article. the pressure may be variable so that the gripping force on an article may be adjusted.

In another version of the invention the grasping means is actuated by reciprocating means such as a pneumatic device to revolve the grasping means forward and backward along the arm.

The grasping means can also have strengthening fibers to provide strength when used to lift or turn articles.

These and other features, aspects, advantages of the present invention will become better understood with reference to the following description, appended claims, and accompanying drawings where:

Fig. 1A is a perspective view, in which the grasping means is intended to extend continuously around the edges, of a grasper for use in the present invention;

Fig. 1B is a transverse cross-sectional view of the grasper of Fig. 1A taken along line 1B-1B in Fig. 1A;

Fig. 1C is a longitudinal cross-sectional view of the grasper of Fig. 1A taken along line 1C-1C in Fig. 1A;

Fig. 1D is a transverse cross-sectional view similar to the view of Fig. 1B of another grasper for use in the present invention;

Fig. 2 is an illustration of the use of a cone-shaped device to expand a grasper as it is being positioned over an arm of a manipulator;

Figs. 3A, 3B and 3C show a portion of a manipulator according to the present invention being used for grasping and releasing an egg;

Figs. 4A-4F show a manipulator according to the present invention being used for grasping a pill and depositing the pill in an orifice;

Figs. 5A, 5B and 5C show a screwdriver according to the present invention being used for inserting a screw into a substrate;

Fig. 6 shows a hex driver according to the present invention being used for applying a hex headed nut to a bolt;

Fig. 7 sows a manipulator according to the present invention being used for applying a hex socket head screw to a substrate;

Figs. 8A, 8B and 8C show a manipulator according to the present invention being used for picking apples;

Figs. 9A and 9B show a manipulator according to the present invention provided with a remote activator;

Fig. 10 shows another version of a manipulator according to the present invention with a different type of remote activator;

Figs. 11A-11J each show a manipulator with a grasper having features such as radial projections, circumferential or longitudinal surface ridges, angularly oriented radial projections, angularly oriented surface ridges, adhesive means applied to the surface, a surface being pitted or roughened to improve grip, and fibers for strengthening located between the inner and the outer walls;

Fig. 12 shows a manipulator having a grasper with Velcro (Trademark) strips on its inner and outer wall sections for increasing the grip between the grasper and the article to be grasped;

Figs. 13A and 13B show the operation of a manipulator adapted for the grasping of a number of identical small parts and then releasing those parts at a specific location;

Fig. 14 shows a version of the manipulator adapted for holding an object by suction;

Fig. 15A shows a manipulator having a grasper that is able to spread laterally to grasp an object larger in diameter than itself;

Fig. 15B shows a manipulator having a grasper equipped with a valve for inflating the grasper so that the insides of a box can be grasped tightly when the grasper is inflated;

Fig. 16 shows a manipulator having a grasper equipped with a valve for inflating the grasper to increase the pressure on an article;

Fig. 17 shows a version of a manipulator equipped with a pneumatic device for revolving the grasping means forward and backward along the arm; and

Fig. 18 shows a manipulator having a grasper with absorbent material on its surface.

The present invention is directed to a method for grasping articles, and manipulators used according to the method.

As shown in Figs. 3A and 3B, a manipulator 10 according to the present invention comprises an elongate arm 12 and a grasper or grasping means 20 on the exterior surface of the arm 12.

The grasper 20 comprises an inner tubular wall section of flexible material and an outer wall section also of flexible material. The inner and outer wall sections form a closed, continuous, double-wall structure. by "closed, continuous, double-wall structure" is meant that the grasper, which is typically tubular, has a continuous wall formed into a double-wall defining a closed volume within the double-wall. The inner wall section is that portion of the wall that forms the inner surface of the grasper 20 in its configuration when under consideration. By outer wall section there is meant that portion of the wall which forms the outer surface of the grasper 20. The outer wall section can be of irregular shape and neither wall section necessarily forms the entire inner or outer surface of the double-wall structure. The grasper 20 generally is open at both ends permitting the manipulator arm 12 to extend completely therethrough.

The grasper 20 preferably comprises two concentric tubes of flexible material of arbitrary cross-section joined at their annular ends. The tubes can be circular, triangular, rectangular, square of any other shape in cross-section. The wall sections can be produced so that they form a continuous, closed double-wall structure; they can be joined directly at the ends thereof; or they can be joined by means of additional material, preferably flexible, positioned so as to connect the wall sections. This additional material can be, for example, a tubular patch which also forms part of the continuous, closed double-wall structure. The inner and outer wall sections are capable of revolving axially when the outer wall section is subject to a force in an axial direction and the inner wall section is at least partially restrained from axial motion in that direction. The annular volume or region between the double-wall can contain a friction reducing means, such as a gas, liquid, grease, particulate solid or the like, if desired to facilitate axial motion of one wall section with respect to the other.

It is preferred that the grasper has substantially uniform properties, particularly unstressed circumference (it can, but need not be, circular in cross-section) through substantially the length of its inner and outer walls. This is preferred in order that the grasper has the same functional performance, for example, axial pressure exerted normal to the arm or to the substrate, irrespective of the position along the arm of substrate onto which it is revolved. Such uniformity of unstressed circumference results if the double-walled tube is produced by turning a flexible tube inside-out (or outside-in) along half of its length sot hat originally opposite ends are joined together. The friction-reducing means is provided within the resulting double-wall. The double-walled tube can be made by joining together respective ends of two concentric tubes; in this case there generally is a different in unstressed circumference between what is initially the inner and what is initially the outer wall, but it need not be substantial. Preferably the maximum unstressed circumference along the inner and outer walls is less than 20%, more preferably less than 10%, especially less than 5%, particularly less than 2% greater than the minimum unstressed circumference.

A typical tubular grasper 20 for use in this invention is illustrated in Figs. 1A, 1B, 1C, 2, 3A and 3B. As shown in these figures, the tubular grasper 20 comprises an inner wall section 32 and an outer wall section 34. the wall sections are joined to form a continuous, closed double-wall structure.

The grasper 20 can be of any length sufficient to revolve on the arm 12 to grasp an article. Generally the grasper is less than about 3.7 meters (12 feet) in length, and more frequently less than about 0.6 meters (2 feet) in length. Typically grasper are from about 2.5 cm (1 inch) to about 75 cm (30 inches) in length, and in particular are from about 15 cm (6 inches) to about 30 cm (12 inches) in length, depending on the article to be grasped. The ratio of the length to the inner diameter of the grasper, both with and without a friction reducing means, is greater than 1, and preferably is greater than about 3.

Each wall section of the grasper comprises a flexible material. The wall sections are preferably from about 0.025

cm to about 2.5 cm (about 0.001 inch to about 1 inch) thick, more preferably from about 0.50 cm to about 6.25 cm (from about 0.02 inch to about 0.25 inch) thick, and more preferably from about 1.25 cm to about 2.5 cm (from about 0.05 to about 0.1 inch) thick. Preferably the flexible material is capable of being folded back on itself to form a continuous loop (although the continuous loop of material can actually be formed by techniques, e.g. molding and extrusion, other than folding the material back on itself). The material can have an elongation to break (ultimate elongation) of greater than about 40%, such as greater than about 100%, or greater than about 200%, or about 500% up to about 900% as determined by ASTM test D412-83.

Preferably the material of each wall section of the grasper is polymeric, and can be elastomeric polymer. The particular elastomer used can be selected to provide the desired chemical, electrical or mechanical properties, for example, UV resistance, abrasion resistance, solvent resistance, etc., for the end use contemplated. For ease in manual expansion of the grasper over an article to a relatively large extent, preferably the material of each wall has a tensile stress at 100% elongation (ASTM Test No. D412-83) less than about 150 psi, and preferably less than about 130 psi. Preferably the wall sections of the grasper are sufficiently stiff that when an axial force is applied at one end of the grasper in a direction toward the other end of the grasper, the grasper does not buckle, but rather axially revolves on the arm 12. This allows the grasper to be used to grasp an article that is inaccessible, such as a recessed screw.

The material comprising the double-wall is chosen from at least two considerations. Firstly, it must allow the revolving action necessary for installation onto the arm and the substrate to be grasped. The properties of interest here include flexibility, tensile stress at a chosen elongation, elongation to break and ability to retain the friction-reducing means. The second consideration is that it must adequately grasp the article without adversely affecting the article grasped, with a view to the environment in which the article is grasped. For example, if it is used in particular environments it may need a certain mechanical strength, abrasion resistance, cut resistance, moisture impermeability, etc. If it is to have an electrical function it may be required to be of high resistivity as an insulator, of low resistivity as a screen or as a conductor for providing electrical charges to a grasped article, or of intermediate resistivity as for stress-grading. It may have a certain specific impedance at a certain frequency, it may need anti-tracking properties, or it may need resistance to erosion under high electrical discharge, etc. where it is to be used in difficult environments it may need compatibility with certain sealing materials, U.V. resistance, fungal resistance, oxidation resistance, resistance to stress-relaxation, flame resistance, resistance to solvents, or low water up-take, etc. Such features are known to be required of certain prior art products, for example, heat shrinkable sleeves, and the person skilled in the art of polymer formulation will know how to prepare suitable materials. After reading this specification he will be able to prepare various new and inventive articles that combine the ability to be installed by the revolving action described herein, and any one or more of the above functional requirements.

Illustrative elastomers which can be employed are natural rubber, polyisobutylene, polyisoprene, isobutyleneisoprene copolymers, polybutadiene, styrene-butadiene copolymers, ethylene-propylene copolymers, ethylene-propylenediene terpolymers, polychloroprene, acrylic rubbers such as ethylene-ethyl acrylate copolymers, epihalohydrin homopolymers and copolymers, nitrile rubbers such as acrylonitrile-butadiene copolymers, silicone rubbers such as polydimethylsiloxane, polysulfides, fluorocarbon elastomers such as hexafluoropropylene-tetrafluoroethylene co- and terpolymers, polyurethanes, and the like. Thermoplastic elastomers such as segmetned polyether ester block copolymers, polyester urethanes, plyether urethanes, and the like can also be used.

The polymeric material can contain a plasticizer, such as an oil, reinforcing fillers, stabilizers, flame retardants, additives to improve the electrical properties such as anti-tracking additives or conductive particles and the like. A preferred polymeric material for certain uses is disclosed in commonly assigned patent application Serial No. 20,633 filed March 19, 1987 filed concurrently herewith, the disclosure of which is incorporated herein by this reference. The material may be cross-linked, for example chemically or by electron beam radiation. Other materials that may be incorporated include thermoplastic polymers such as elastomers, or metals, for example aluminum or steel.

The wall sections can also be of fabric, for example a braid or woven tubular fabric. The fiber used can be elastomeric, thermoplastic, cellulosic, proteinaceous, mineral, glass, ceramic, metallic or the like or mixtures of these. The construction, e.g. the weave, of the fabric preferably permits radial expansion of the grasper while providing increased axial strength. Heat-recoverable fabrics can be used.

The wall sections can be of composite materials. For example the wall sections can comprise an elastomeric material reinforced with fibers or fabric. The reinforcing fibers can be polymeric, glass, cellulosic, carbon, graphite, metallic, ceramic or the like. The fibers can be oriented axially or helically for improved tensile strength. Further, the wall sections can comprise segments, for example, strips of different materials to provide different properties along the walls, if desired. The only requirement is that the various wall sections be sufficiently flexible to form a double-wall tubular grasper capable of revolving axially as described herein.

As shown in Fig. 1D, one or both of the wall sections can comprise a plurality of layers of material formed for example by lamination or coextrusion. For example, the inner wall section 32 of the double-wall structure can comprise an interior layer 32A (i.e. the layer facing the closed area within the double-wall structure) of butyl rubber which is an effective gas diffusion barrier and an outer layer 32B of ethylene-propylene-diene terpolymer rubber which has excellent weathering properties. Similarly, the outer wall section 34 can comprise an interior layer 34A and an outermost layer 34B. The wall sections can be selected to provide desired properties, such as corrosion resistance, abrasion resistance, or other physical or chemical properties, depending on the particular end use contemplated. The layers of such wall sections can be of thermoplastic material, elastomeric material, metal, fabric, etc. as desired.

The inner and outer wall sections can be of the same material. Alternatively, they can be of different materials. They can have the same thickness or can differ in thickness. Each wall section can vary in thickness along its length. The inner and outer wall sections can be produced in a manner such that they directly form a continuous, closed, double-wall structure such as by extrusion or molding; they can be formed as a single tube which is folded back on itself and the ends joined together; or they can be formed independently, and arranged in a concentric configuration with the ends joined together. The joint between the ends can be permanent or of a temperature nature, e.g. by a removable clamp or patch. The ends can be joined directly or by the use of one or more additional segments of material, for example, a tubular strip of flexible material can be inserted between the ends, if desired. Thus, the closed double-wall structure can contain addition wall sections besides the requisite inner and outer wall sections and, as discussed above, the inner and outer sections can each comprise several different components to provide the desired properties.

When joined together, the inner and outer wall sections form a continuous, closed, double-wall structure as illustrated in Figs. 1A, 1B and 1C. The inner and outer wall sections are capable of axial motion with respect to each other. By axial motion is meant that the wall sections are capable of motion in a direction along the axis of the tubular grasper. The wall sections are not restricted to axial motion and generally are capable of radial motion. When the outer wall section is subject to a force in an axial direction, and when the inner wall section is at least partially restrained from axial motion in that direction, the double-wall structure is capable of continuing axial revolution, that is, can undergo more than one complete axial revolution.

By continuing axial revolution we simply mean that relative sliding motion or shear between first and second walls of the grasper can be continued such that the first and second walls exchange position and then return to their original configuration. Thus, the article may be revolved along an elongate member and left in any desired position. The first and second walls may of course be indistinguishable from one another, except for the fact that at any given time one is an inner wall adjacent the substrate and one is an outer wall overlying the inner wall. Then the portion of wall material that constitutes each wall will continuously change as the revolving action takes place. When we refer to a first, second, inner or outer wall we refer merely to a portion of wall identifiable for the time being by its position and do not imply that it has any structural uniqueness. The revolving action may be pictured best perhaps by imagining a longitudinal axial section of the grasper over a cylindrical substrate such as the arm on which the grasper operates. The tube will appear as a Caterpillar-track on either side of the substrate (Caterpillar is a trademark). The tube can progress along the substrate by the Caterpillar-tracks revolving. This involves shear between the inner and outer walls constituting the Caterpillar-track, and will generally avoid shear between the inner wall and the substrate.

When we refer to the grasper with an outer wall and an inner wall we do not preclude additional walls or layers, providing the revolving action is still able to take place.

To assist in the motion between the wall sections and thus the revolving motion of the grasper 20 on the arm 12, friction-reducing means 36 can be contained within the closed, double-wall structure, i.e., in the closed area between the inner and outer wall sections. Such means can be a gas, liquid, solid, or semi-solid, such as grease or the like. The friction reducing means can permit relative motion by keeping the wall sections from contacting each other, by acting as a lubricant, or both. By the term lubricant there is meant a substance that lowers the friction between the wall sections. Preferably the friction reducing means wets both wall sections. By the term "wet" there is meant that the dihedral angle between the friction reducing means and the wall sections is less than 45°.

If the interior surfaces of the double-wall structure are of materials having a sufficiently low coefficient of friction, friction reducing means may not be required.

Various friction reducing means and combinations of friction reducing means can be used. The friction reducing means can comprise a solid or semi-solid material. Solid materials which can be used include particulate materials, for example powdered talc, corn starch, graphite powder, glass beads, ceramic beads, polymeric beads, e.g. of PTFE, metal balls, e.g. of iron, low melting alloys or the like which can impart conductive and/or magnetic properties or the like to the article. A continuous solid in the form of a thin coating can also be used as the interior surface of one or both of the wall sections. The solid is preferably one which has good lubricity, for example ultra high molecular weight polyethylene, polytetrafluoroethylene (PTFE) or the like. Also as noted above, the interior surfaces of the double wall structure can be of a material which has inherent lubricating properties, in which case, no friction reducing means need be placed in the space between the walls. One or both of the interior surfaces of the double-wall structure can be provided with a plurality of protuberances or bumps as the friction reducing means.

Semi-solids which can be used include greases, gels, pastes and the like. Preferably both semi-solids and liquids are non-newtonian, exhibiting thixotropicity and pronounced pseudoplasticity, wherein at shear rates greater than 1000 reciprocal seconds the viscosity is less than

10,000 centipoise. In the case of semi-solids, a small yield stress, such as exhibited by Bingham fluids, is preferred. Examples of such semi-solids include very light greases, having NLGI ratings of 00 or 000 such as hydrocarbon based MGA-00 manufactured by Fiske Brothers Refining Co. of Toledo, Ohio, and light silicone greases.

Liquids can also be used as the friction reducing means. Liquids which have a viscosity greater than about 1 centipoise at 20°C and at shear rates less than about 100 reciprocal seconds can be used, as well as liquids having a viscosity greater than about 5, or greater than about 50 or greater than about 200 centipoise at 20°C. Examples of such liquids (which term includes compositions often referred to as gels) include the following: a polyhydric alcohol such as glycerin or a glycol, or polyhydric alcohol-based or water-based solutions containing a soluble polymer such as a polyacrylate, polymethacrylate, polyacrylamide, polyethylene oxide, polyamide, polyamine, guar gum, xanthan gum, alginate, maleic anhydride copolymer, polyvinyl pyrrolidone, polyvinyl alcohol, cellulose derivative such as hydroxypropylcellulose, or oil such as a silicone oil, hydrocarbon oil, mineral oil, or vegetable oil. Where solutions, or other combinations of a dispersed and a continuous phase are used, dispersing, solubilizing, gelling or other stabilizing agents may be used. Such agents are thought to act by making possible an extended weak hydrogen-bonded or ionic-bonded matrix throughout the liquid that can be ruptured by shear.

Preferred lubricant solutions comprise very dilute solutions of very high molecular weight, generally slightly gelled, polymers. Preferred molecular weights vary from greater than 1 million to greater than 6 million, depending on the particular polymer used. Preferred concentrations vary from 0.05% to 20% by weight. A commercially available example is an aqueous lubricant called Polywater F (Trademark) from American Polywater Corp. of Stillwater, Minnesota.

Thickened aqueous or non-aqueous polymeric solutions are however preferred. A first example is a solution comprising about 90% by weight propylene glycol, 0.05 to 5%, preferably about 0.5% by weight, slightly anionic polyacrylamide having a molecular weight greater than 6 million, and the remainder water. The primary function of the water is as a solubilizing agent for the polyarylamide. A second example is a solution comprising 0.05% to 5% of polyacrylamide in water. Further ingredients such as biocides, boundary lubricants or stabilizers may be added.

Another specific example is a solution or dispersion of very high-molecular-weight (greater than 1 million molecular weight) hydroxypropylcellulose in propylene glycol. Preferably the hydroxypropylcellulose is used in a weight percentage of 0.05%-20%, more preferably in a weight percentage of 0.1%-10%, most preferably in a weight percentage of 0.3-3%. The solution or dispersion may also contain a salt of a fatty acid soluble in propylene glycol such as sodium octanoate to serve as a wetting agent. Preferably the fatty acid sale is present in a weight percentage of 1-30%, more preferably in a weight percentage of 4-20%, most preferably in a weight percentage of 5-10%. Small quantities of other stabilizers may be added to serve as anti-oxidants, fungicides, etc. An example is Ultranox 254 (Trademark), which is polymerized 1,1,1-trimethylhydroxyquinoline.

The friction reducing means can be a gas such as air, oxygen, carbon dioxide, nitrogen, acetylene, or the like. However, gases are less preferred because when the grasper is rolled onto an article to be grasped, the gas can be forced into the portion of the grasper not on the arm or the article. This can make it difficult to revolve the entire grasper into place.

If a gas is used, preferably the pressure of the gas is greater than atmospheric pressure. Preferably the pressure of the gas is from about 6.9 to about 138 kPa (from about 1 to about 20 psig), more preferably from about 6.9 to about 69 kPa (from about 1 to about 10 psig), and most preferably from about 13.8 to about 34.5 kPa (from about 2 to about 5 psig). The gas can be selected for desirable properties for the particular use. When grasping fragile articles, sufficient gas can be placed in the annular region between the two wall sections that the gas cushions the fragile article from damage. The gas can be formed in situ from solid and/or liquid components within the annular space defined by the double walls of the connector. For example, carbon dioxide can be generated in situ from a mixture of acetic acid and sodium bicarbonate. The components can be separated by a barrier such as a polyethylene film until the grasper is to be used. Then breaking of the barrier permits the components to react and generate the gas within the space between the wall sections. Similarly, acetylene gas can be generated in situ from calcium carbide and water.

The friction-reducing means will in general require some means to prevent or restrict its own displacement at least during initial revolving action onto an arm or article. Before preferred examples of the friction-reducing means are given therefore, the means for restricting displacement will be explained since in preferred embodiments it is a property of the friction-reducing means rather than something physically separate. When both walls have to be expanded as the grasper is revolved over an end of an article or onto the arm, a separating fluid has a tendency to be driven away from that region of the tube subjected to greatest expansion which, unfortunately, is where it is needed.

Whilst we wish not to be bound by any theory, we believe that the friction-reducing means, when a liquid, serves by maintaining hydrodynamic lubrication, presumably in addition to boundary lubrication. We prefer that lubrication can be maintained between the two walls of the double-walled tube under a pressure gradient along the axis of the grasper of 27 kPa per cm (9.9 psi per linear inch). In the absence of the means for restricting, substantially all separating fluid may be displaced, possibly leaving an adsorbed monomolecular layer of lubricant at each surface. The conditions under which hydrodynamic lubrication (or whatever phenomenon is responsible) must be maintained will of course depend on the particular application but the following information may be helpful. Displacement of friction-reducing means may be rate dependent, and a very quick installation may be successful where a slow one is not, simply because less time is available for the friction-reducing means to be displaced. Nonetheless, some means for restriction will be preferred and a simple gas (which is preferred in the prior art double-wall tubes, but whose sole presence is excluded from the article defined above) being perfectly fluid and having no means to prevent its displacement will generally not function as desired, however quickly one attempts to revolve the grasper over the arm or article. Furthermore, the speed at which one is able to revolve the grasper will depend on its size, and on the shape and size of the substrate over which it is to be revolved.

The friction-reducing means may be restricted from displacement by being physically attached to the inner and outer walls. For example, the walls may have a low friction coating. A second possibility is the provision of some means that deforms a second region of the article, preventing flow of friction-reducing means away from a first region where it is needed.

We prefer, however, that the friction-reducing means is a liquid having such rheological properties that it can continue to provide hydrodynamic lubrication under the conditions described herein. We prefer also that the liquid wets the surfaces of the wall of the double-walled tube, preferably at a dihedral angle of less than 80°, more preferably less than 45°, especially less than 30°. The correct rheological properties and the ability to wet the walls result, it is thought, from some sort of weak bonding network throughout the friction-reducing system to the walls that allows the walls to slide past each other in shear but resists displacement of the friction-reducing means that would otherwise occur due to the tension in the outer wall and the force of installation which effectively forces the two walls together.

Preferred behavior of the lubrication system is reflected in such properties as the change in viscosity with shear rate. We prefer in fact that the friction-reducing means is a non-newtonian, particularly highly non-newtonian liquid (which term includes semi-solid). It is preferably pseudo-plastic (viscosity decreases with increasing shear) and/or is a Bingham fluid (which means that it has certain non-zero yield stress). Preferably the viscosity at 20°C is less than 10,000, especially less than 5,000, particularly less than 1,000 centipoise at shear rates of greater than or equal to 100, particularly greater than 500, especially greater than 1,000 reciprocal seconds. We also prefer that the viscosity at 20°C at a shear rate of 1 reciprocal second is greater than the following, in order of ascending preference: 1, 50, 100, 200, 5,000, 10,000 centipoise.

We have discovered that in addition to preferred absolute values of viscosity the rate of decrease of viscosity with shear rate, i.e. the degree of non-newtonian behavior, is important. We particularly prefer that, at least over a range of from 1-100 reciprocal seconds, the viscosity drops by at least a factor of 5, 10, preferably 15, especially from 15-30. This factor is not particularly temperature dependent, and we prefer that it holds at 20°C.

A further property desirably possessed by the friction-reducing system is pituity. This property is related to the cohesive strength of the liquid and can be pictured as stringiness. Pituity must be distinguished from viscosity. The simplest demonstration of pituity is seen is a syringe needle is immersed in a beaker of pituitous fluid beneath the surface of the fluid. If the plunger of the syringe is raised, a pressure-driven flow will be set up whereby the fluid is drawn into the syringe. If the needle is now lifted so that it is above the surface of the fluid by more than the diameter of the needle, a pituitous fluid will continue to be drawn up through the air into the syringe. A non-pituitous fluid will no longer be drawn up into the syringe under such conditions. It may be quantified in terms of extensional viscosity.

Pituity may be measured as follows. A sample of the liquid to be tested is placed in a tin can approximately 0.5 litres and of approximately 8 cm diameter, to a depth of at least 5 cms. A blade is inserted in the liquid and the force required to remove it is measured using an Instron (trademark) tensile tester model 112 equipped with a 2 kg load cell. The Instron is calibrated to 100 grams full scale. The blade (which preferably has at least one hole therethrough to increase drag caused by the liquid) is placed vertically in the upper jaw. At 100 grams full scale the Instron recording pen is set to zero. The scale is then changed to 20 grams full scale and the pen re-balanced to zero. A chart recorder set to 200 mm per minute is found to be suitable for recording the results. The can with the liquid is placed under the blade so that the blade is centered. The cross head is moved so that the blade just contacts the surface of the liquid, and this is done at an approach speed of 20 mm per minute. The counter is set to 000 mm, the cross head to 50 mm, and the stop mode is activated. The liquid is then entered, and when the minimum limit is reached a stopwatch is started. The counter is reset to 000 mm, the minimum limit is deactivated, and the cross head speed is set to 1000 mm per minute.

After 25 seconds the recording charge and the pen are started. After 30 seconds the cross head is started in an upwards direction.

The force is recorded as a function of time. The curve obtained shows a sharp spike indicating a sudden force which then dies. This is due to the inertia of the blade. The spike may be ignored. The force then rises quite sharply with time to reach a peak value (Fp grams) and it then decreases gradually down to some residual value which represents the weight of the liquid remaining on the blade after it has been removed from the bulk of the liquid.

The peak force (Fp) and the area under the curve as defined by this test give an indication of the pituity of the liquid. The area under the curve is taken as the area bounded by the upper part of the curve and the time axis and a straight line extension of the rise side down to the time axis, and tangent to the inflection point of the fall side down to the time axis. The area is given herein as E in units of grams second. Three measurements of each liquid are to be made, if possible, and an average taken.

We prefer that the friction-reducing means has a pituity given by Fp greater than 1 gram, preferably greater than 1.5 grams, especially greater than 2 grams, particularly greater than 7 grams, more particularly greater than 10 grams. The value will generally be less than 30 grams.

The value of E is preferably greater than 4 grams, especially greater than 5 grams, particularly greater than 10 grams, more particularly from 15 to 100 grams. The value will generally be less than 200 grams.

We prefer that the friction reducing means has an Fp value within the above ranges and an E value within the above ranges.

The above properties of the friction-reducing means should apply under conditions of use, particularly at ambient installation temperatures which may range at least from -40° to +60°C but is more usually -10 to +25°C. In many instances however the grasper may experience high temperatures during service which may alter the properties of the friction-reducing means, for example pituity may be reduced after high temperatures or prolonged lifetimes. A shelf-life of one year at 50°C, especially two years at 60°C, is preferred.

If too much friction reducing means is used, the wall sections can fail at the juncture between the inner and outer wall sections. Therefore preferably the thickness of the friction reducing means is sufficiently small that the wall sections are separated by a distance of no more than about 10 times the thickness of the minimum thickness of the wall sections.

The grasper 20 can be made by a variety of methods. The manner in which it is made is generally not critical. In a preferred method of manufacture, a tube approximately double the desired length of the tubular article is formed by, for example, extrusion. The ends of the tube are folded over until they form an overlap region. Solid, liquid or semi-solid lubricant means can be added at this point. The ends are secured together, for example by means of an adhesive, forming the continuous wall of the double-wall structure. If a solid lubricant such as polytetrafluoroethylene (PTFE) is used, a layer of PTFE can be laminated or bonded to the outer surface of the initial tube before the ends are folded back. If a grease is used, the material can be spread onto the outer surface of the tube before the ends are folded back.

Another preferred method comprises extruding individual tubes, one of smaller diameter than the other, arranging the tubes in concentric relationship, and then bonding the ends of the tubes together. The friction reducing means, if solid, can be advantageously applied to the outer surface of the tube of smaller diameter. Gaseous, liquid and particulate or powdered friction reducing means can be inserted between the concentrically arranged tubes prior to sealing both ends thereof. The friction reducing means can also be added into the space between the walls by injecting the appropriate material through a relatively small opening in the wall and then sealing the opening. The walls can be provided with a one way valve, preferably one that is relatively flat, to facilitate injecting the friction reducing means into the space between the closed, double-walls. This is particularly advantageous if a gaseous friction reducing means is used.

The grasper can be formed by any other method for example molding, casting, or the like. The walls of the grasper can be formed by dip coating a solid cylindrical object comprising a material which on subsequent treatment, e.g. crushing, dissolving, melting or the like, forms the friction reducing means.

The wall sections are joined together by any technique suitable for the particular material of the walls. Such techniques include, for example, adhesive bonding, fusion bonding, ultrasonic welding, vulcanizing, clamping, taping or the like. Joining of the walls can include the use of an additional segment of flexible material, if desired, for example to reinforce the joint area, e.g. by use of a patch or strip of flexible material. Preferably the walls are directly joined together using a lap, butt, scarf joint or the like as shown in region 37 of Fig. 1C. Preferably the connector comprises a flexible material capable of being radially expanded (i.e. stretched).

When the grasper is on the exterior of the arm, the circumference of the inner wall section of the grasper 20 before it is placed on the arm is no greater than, and preferably is less than, the outer circumference of the arm 12 so that the grasper 20 does not slide but rather revolves on the arm. Preferably the unstressed inner circumference of the grasper is no greater than, and more preferably is less than, the outer circumference of the article to be grasped so that the grasper 20 revolves onto the article and firmly grasps the article. This is not necessary, if the grasper is provided with supplementary means to assist in grasping the article, such as ridges, projections or fingers. By "unstressed" there is meant the inner circumference of the grasper before any fluid or solid is placed in the annular region and before it is stretched by being placed on any object, i.e. before it is positioned on the arm or on an article. In addition, preferably the unstressed inner circumference of the grasper is sufficiently small that both wall sections of the grasper exert a force toward the arm normal to the surface of the arm. With both wall sections exerting a force on the area and the grasped article, the article and arm can be held together with up to double the force provided by a grasper having only a single wall of the same thickness as the inner wall thickness. The force exerted by the inner wall section can be exerted directly on the article and the arm. The force exerted by the outer wall section is exerted on the arm and the article through the inner wall section and the friction reducing means, if any.

The term "circumference" is used herein to refer to the outside periphery of the arm or an article, the outside periphery of the grasper, and the periphery of the inside of the grasper, regardless of their configuration, i.e. whether they are circular, oval, square, star-shaped or the like in cross-section.

The inner and outer circumferences of the grasper 20 can be of any desired dimension depending on the circumference of the arm 12 and the circumference of the article to be grasped. A grasper 20 used in this invention can be less than about 51 cm (20 inches) in unstressed inner diameter (about 160 cm (63 inches) in circumference), and generally is from about 0.8 mm to about 15 cm (from about 1/32 inch to about 6 inches) in unstressed inner diameter (from about 0.25 cm to about 48 cm (from about 0.1 inch to about 19 inches) in inner circumference). The outer diameter of the grasper similarly can be of any desired size, and typically is less than 1.27 meters (50 inches), generally less than 25.4 cm (10 inches). In the presence of a friction reducing means, preferably the ratio of the outer circumference of the arm and the grasped article to the inner circumference of the grasper before it is placed on the arm is no more than about 5.

The arm 12 of the manipulator 10 can be substantially any elongate article on which the grasper 20 can revolve. The arm can have any shaped external periphery, i.e. it can be circular oval, square, star-shaped or the like in cross-section, and the cross-section can change in size and shape along the length of the arm. Preferably the arm is circular in cross-section. The arm can be a solid rod or can be hollow, i.e. tubular. Preferably the arm has a cylindrical cross-section for ease in revolving the grasper along the arm.

The material of the arm can be substantially any rigid material that is compatible with the material of the grasper. for example the arm can be metallic or polymeric. If polymeric, the polymer can be reinforced with fibers or fabric.

The arm is sufficiently long that the grasper can revolve back and forth along the forward portion of the arm while the rearward portion of the arm can be manipulated for approaching and grasping an article.

The circumference of the arm depends upon the size of the article to be grasped. Preferably the circumference of the arm and the circumference of the article to be grasped are about the same so that the grasper exerts the same force onto the arm as it exerts onto the article. However, the arm can have a slightly larger circumference than that of the article so that less force is required for revolving the grasper onto the article than onto the arm. Generally the maximum diameter of the article grasped from the outside is less than or equal to the outer diameter of the arm, but that is not necessary, and it is possible for the diameter of the grasped article to be greater than the outer diameter of the arm.

The arm can be a part of a device that is manipulated by hand. For example the arm can be the shaft of the srewdriver, a portion of a fruit picker, the shaft of a spark plug wrench, or the shaft of a bolt driver. alternatively, the arm can be a portion of a machine that automatically manipulates the arm, such as the arm of a robot or the working end of an industrial machine that picks up articles off of a conveyor belt.

Preferably the grasper 20 is made an integral part of the arm 12 by securing a portion of the grasper to the forward portion 13 of the arm 12. As shown in Fig. 3A, a portion of the grasper 20 is permanently affixed to the arm 12 by attaching means such as an adhesive 40. The adhesive 40 can be provided as a band around the external surface of the arm 12.

The attaching means need not be a bonding agent such as the adhesive 40. It can also be a mechanical device, i.e. a screw, bolt, retaining ring or the like; a solvent forming a solvent bond between the grasping means 20 and the arm 12;

or a heat bond such as by heat welding when both the arm 12 and grasping means 20 are formed from polymeric material. In an exemplary version, the bonding agent for a PVC (polyvinylchloride) arm and a PVC grasper can be a solvent for PVC such as THF (tetrahydrofuran) or a solution of PVC in a solvent. More than one attaching means can be used; for example, a mechanical fastener and a bonding agent can be used in combination.

In the version of the invention where an attaching means 40 is used, although the grasping means can axially rotate on the arm 12, it cannot be revolved off the end of the arm because of the attaching means. A suitable bonding agent can be a two-part epoxy resin system.

To position the grasper onto the arm, an end of the grasper is expanded to the outer circumference of the arm and an end of the arm is inserted into the expanded open end of the grasper. The end of the grasper can be expanded manually if the difference between the inner circumference of the grasper and the outer circumference of the arm is not too great and/or if the flexible material of the grasper is easily stretched, i.e. it has a relatively low durometer hardness.

With reference to Fig. 2, where there is a significant difference in the internal circumference of the grasper 20 and the external circumference of the arm 12, e.g. up to about 3 to about 5X or even greater, the grasper can be expanded over, for example, a cone-shaped mandrel, e.g. a funnel 52. The grasper is positioned over the narrow end of the funnel and an axial force is applied to the outer wall section causing the grasper to revolve onto the funnel, expanding as it travels toward the larger end of the funnel. Continued axial force on the outer wall section revolves the grasper from the funnel and onto the arm.

A method according to the present invention for using the manipulator 10 is demonstrated with reference to Figs. 3A, 3B, and 3C. As shown in these figures, the manipulator 10is being used for grasping a fragile object such as an egg 54. As shown in Fig. 3A, the manipulator 10 is positioned so that the forward portion 13 of the arm 12 is proximate to the egg 54. Preferably the grasper 20 is revolved onto the arm so that none of the grasper extends beyond the forward portion 13 of the arm 12. Then the article 54 is grasped by axially revolving the grasper 20 along the exterior of the arm 12 beyond the forward portion 13 of the arm in the direction of arrows 55, and as shown in Fig. 3B, onto the article 54. This is effected by applying an axial force onto the outer wall section of the grasper 20 toward the egg 54 while the inner wall section of the grasper 20 is restrained from axial motion in that axial direction. The grasper 20 is restrained by friction between the inner wall section of the grasper 20 and the exterior of the arm 12, as well as the adhesive 40 at the forward portion 13 of the arm 12.

The inner circumference of the inner wall section of the portion of the grasper 20 extending beyond the forward portion of the arm is sufficiently less than the outer circumference of the egg 54, that the grasper 20 exerts a force towards the egg 54 normal to the surface of the egg. The grasper 20 is kept from revolving off of the arm 12 by the retaining adhesive 40.

Once the egg 54 is grasped with the manipulator 10, the egg 54 can be moved or transferred to any desired position merely by moving the arm 12. For example, the manipulator 10 can be used for retrieving eggs from a hen house without being attacked by a chicken, and then the eggs can be deposited in a basket or in boiling water for breakfast. Depositing the egg 54 in a basket or other receptacle is easily effected by revolving the grasper 20 away from the article in the direction shown by arrows 56 in Fig. 3C. The egg is released by applying an axial force onto the outer wall section of the grasper in the direction of arrows 56 while the arm is restrained from movement and the inner wall section of the grasper is restrained from axial motion in that axial direction by friction with the exterior surface of the arm 12 and by the adhesive band 40.

With reference to Figs. 4A-4E, a manipulator 60 can be used for placing objects into cavities, such as pills, plugs, suppositories, and the like into body orifices, with substantially no irritation, pain, or likelihood of injury. The manipulator 60 comprises an activating arm or rod 62 having on its forward portion 65 a tubular double-wall grasper 64 held onto the exterior of the rod 62 by an adhesive band 66. The manipulator 60 is being used for depositing a capsule 68 into a body cavity 70 having surrounding walls 72 and an opening 73. Although the rod 62 can be hollow, at least the forward end 74 of the rod 62 must be closed or of sufficiently small internal diameter that the capsule 68 cannot slide into the rod.

To use the manipulator 60, the forward end 74 of the rod 62 is positioned proximate to the capsule 68 with the grasper 64 substantially entirely on the exterior of the rod 62. Then the grasper 64 is axially revolved in the direction shown by arrow 76 in Fig. 4B over the capsule 68. In this version of the invention, it is not necessary that the grasper exert a force normal to the surface of the capsule 68, but only that the capsule 68 or other object to be deposited easily fits into the grasper 64.

The leading end 80 of the extended grasper 64 is placed in the opening 73 of the cavity 70 and the rod 62 is pushed forwardly in the direction shown by arrow 76. The grasper 64 is sized such that its outer circumference, when the grasper 64 is sized such that its outer circumference, when the grasper 64 is off the rod 62, is less than or about equal to the internal circumference of the opening 73 of the cavity 70.

The grasper 64 can be revolved into the cavity 70. Initially, the grasper is almost entirely on the rod with a small portion protruding into the cavity. The capsule is adjacent the forward end of the rod 62.

The next step of the method for depositing the capsule 68 is shown in Fig. 4C. This involves pushing the rod 62 in the direction shown by arrow 76. This results in the grasper being revolved into the cavity with no damage to the walls of the cavity and the capsule 68 being pushed fowardly into the cavity 70. The rod must be sufficiently stiff when under compression so that it can be pushed forwardly.

To remove the grasper 64 and the rod 62 from the cavity, the rod 62 is pulled out of the cavity in the direction shown by arrow 90 in Fig. 4D, thereby revolving the entire manipulator 60, including the grasper 64, out of the cavity 70. Thus, as shown in Fig. 4E, the capsule 68 is deposited far into the cavity 70 with substantially no irritation of the wall 72 of the cavity 70.

Figs. 5A-5C show a screwdriver 100 having features according to the present invention. The screwdriver comprises a handle 102 and an elongated shaft 104 having a tip 106 adapted to fit into a slot 108 in the head 110 of a screw 112. The screwdriver 100 is provided with a double wall revolving grabber 114 on a shaft. The grabber 114 may be affixed to the forward portion of the shaft 104 adjacent the tip 106 by a band of adhesive 118.

As shown in Fig. 5B, the grabber 114 solves a problem commonly associated with screwdrivers, namely how to hold the tip 106 in the slot 108 of the screw head 110. This is effected by revolving the grabber 114 along the shaft 104 and over the screw 112 so that the screw is firmly held in position on the screwdriver 100. Although the screwdriver 100 is shown in Figs. 5A-5C is particularly adapted for slot headed screws, screwdrivers having a grabber can also be used with all types of fasteners such as Phillips head screws.

When the screw 112 is held in position on the screwdriver 100, the screw can be screwed into a substrate 120, and then as shown in Fig. 5C, the grabber can be revolved off of the screw by pushing on the exterior of the grabber 114 in the direction shown by arrow 112 in Fig. 5C.

The screwdriver 100 is especially useful for removing screws from substrates. For example, with reference to Fig. 5C, once the screw 112 is partly unscrewed from the substrate, the grabber 114 can be revolved over the screw 112. Then when the screw 112 is completely unscrewed from the substrate, it remains with the screwdriver and does not fall into a dark and deep recess from which it is impossible to recover. Further the flexible grabber 114 allows for misalignment between the screw and screwdriver.

Another version of the invention is shown in Fig. 6, where a hex driver 130 is provided with a double wall tubular grasper 132. The hex driver has a handle 134 with an axially extending shaft 136. The grasper 132 is on the external surface of the shaft 136 and is held at the forward portion of the shaft by an adhesive band 138. The method for using the hex driver 130 is the same as the method for using the screwdriver 100 of Figs. 5A-5C, except the hex driver is used with hex headed nuts, 139, screws, and other similar fasteners.

With reference to Fig. 7, the present invention is also useful with an Allen hex wrench 140 where the shaft 142 of the Allen wrench is provided with a grasper 114 on its external surface. The Allen hex wrench 140 can be used with socket headed fasteners 146 to securely grasp the fastener as it is being rotated either into or out of a substrate.

Figs. 8A, 8B and 8C show a particularly unique version of the present invention. In this version, a collector 200 has an elongated hollow tubular arm 202 with a grasper 204 at the forward portion thereof. The collector 200 is particularly adapted for removing and collecting fruit from a tree such as apples 206 from a tree branch 208. The arm can be from 6 to 20 feet long, and if desired can be telescoping. As shown in Fig. 8A, by means of an activating means, the grasper can be remotely revolved. The activating means comprises an elongated rod 210 that is used to revolve the grasper 204 off of the arm 202 and onto the apple 206. The grasper is pushed in the direction shown by arrow 211 by a hooked end 213 of the rod 210.

Next the rod 210 is used to pull the grabber 204 downwardly in the direction shown by arrow 212 in Fig. 8B. This deposits the apple 206 into the hollow interior of the arm 202, as shown in Fig. 8C. The apple then falls down through the arm 202 to be collected in a basket 220.

Figs. 9A and 9B show another manipulator 300 suitable for grasping an article 302, where the manipulator is provided with remote activating means. The manipulator 300 comprises a hollow tubular arm 304 with a double-wall grasper 306 on the exterior of the arm and attached to the forward end 308 of the arm by means of an adhesive 310. The adhesive 310 is between the interior wall of the grasper 306 and the exterior wall of he arm 304. The activating means comprises an elongated activating rod 312 having a length about equal to the length of the arm 304. The activating rod 312 is connected to a collar 314 through a rigid or universal joint 316. The length to diameter ratio of the collar 314 is at least 2.5 to avoid binding of the collar on the grasper. The collar 314 surrounds and is attached to the exterior of the outer wall section of the grasper 306 by means of an adhesive 318 at the opposite end of the grasper 306 from the end joined to arm 304. That is, the band 314 is at the trailing end of the outer wall section of the grasper 306.

The rod 312 is sufficiently stiff that it can be used for both revolving the grasper 306 off of and onto the arm 304, i.e. the rod 312 is stiff both in compression and in tension. Because the rod 312 is pivotally attached the universal joint 316 to the band 314, it is possible to remotely activate the grasper 306 from almost any angle.

With reference to Figs. 9A and 9B, the article 302 can be grasped by pushing on the rod 312 to revolve the grasper 306 in a direction shown by arrows 340 toward the article 302 and over the article 302. As shown in Fig. 9B, the grasper 306 remains attached to and remains on the exterior surface of the arm 304 by adhesive and the activating rod

312 remains attached to the exterior of the grasper 306 by adhesive 318.

With reference to Fig. 10, there is shown the grasper 300 shown in Figs. 9A and 9B, but a different remote activating means is used. In this version of the invention, the remote activating means comprises a tube 370 that is coaxial with and surrounds the tubular arm 304. The tube 370 is attached to the exterior of the outer wall section of the grasper 306 by means of an adhesive 372 at the trailing end of the grasper 306. This version of the invention provides a compact device in that the arm 304 and the tube 370 are coaxial.

A variety of alternative versions of the present inventions can be used. For example, when grasping metal objects, the grasper can be formed from a magnetic material; the walls of the grasper can be magnetic or the friction reducing means can be made magnetic. In addition, as detailed below, to be certain that the article grasped is firmly grasped, a variety of supplementary means can be used. For example, an adhesive such as contact adhesive or pressure sensitive adhesive or a gel can be used on the grasper. The grasper can also be provided with one or more projections to facilitate grasping rings, discs or the like.

As stated above, the grasper may be provided with one or more ridges or projections in a variety of orientations for holding a variety of objects. Fig. 11A shows, in a transverse cross-sectional view, a grasper 402 provided with number of projections or fingers 404 which can be either rectangular, circular, or ovoid in shape and whose narrow ends are attached to the grasper 402 so that the projections 404 protrude at an angle approximately normal to the grasper 402. The projections 404 can be attached to the grasper 402 so that they protrude, alternatively, at other angles as well. Fig. 11A portrays the projections 404 on the outer wall section of the grasper 402; as the grasper 402 is revolved along the arm or the object to be grasped, the projections or fingers 404 revolve with the grasper 402 so that they project inwardly from the inner wall section 38 of the grasper.

Fig. 11B shows a grasper 406 with a plurality of ridges 408 arranged circumferentially around the outer wall section of the grasper 406. As with the projections in Fig. 11A, the ridges 408 revolve with the grasper 406 so that they project inwardly from the inner wall section of the grasper 406. The ridges 408 may be rectangular, semicircular, or of other shapes.

Fig. 11C shows a grasper 410 with a plurality of longitudinally arranged ridges 412. Fig. 11D shows a transverse cross-sectional view of a grasper 410 of Fig. 11C with the ridges 412 protruding from the interior wall section 38 of the grasper 410 after rotation. As with the circumferentially arranged ridges shown in Fig. 11B, the longitudinally arranged ridges 412 can be rectangular, semicircular, or of other shapes.

Fig. 11E shows the outer wall section of a grasper 414 which carries a plurality of projections 416 on its outer wall section arranged in a staggered arrangement so that the individual projections 416 form rows or lines at an acute angle to the longitudinal axis of the grasper 414.

Fig. 11F shows the outer wall section of a grasper 418 which carries a plurality of continuous ridges 420 on its outer wall section, the ridges 420 arranged at an acute angle to the longitudinal axis of the grasper 418. This arrangement of ridges can be useful for transmitting torque to the object to be grasped and can allow the grasper to serve as a torque wrench without the need of making an additional mechanical contact with the object. This could prove useful for accomplishing such tasks as the installation of a spark plug into a crowded engine block as shown in Fig. 11G. In Fig. 11G, an arm 12 is surrounded by a grasper 422 which has a plurality of angled ridges 424 on its inner and outer wall sections. The grasper 422 is used to hold and turn a spark plug 426 so that the spark plug 426 is installed into an engine block 428. The form of the invention shown in Fig. 11E, with a plurality of staggered projections 416, can also be useful as a torque wrench. To allow torque to be transmitted in both directions, the ridges could be provided in the form of a diagonally-crossed mesh of cloth or other material.

In addition, to be certain that the article to be grasped is firmly grasped, means to assist in holding an article can be provided. For example, an adhesive such as a contact adhesive or a pressure-sensitive adhesive or a gel can be used to coat the wall sections of the grasper. The wall sections of the grasper can be provided with a covering of a barbed or hooked fabric such as Velcro (trademark) fabric to provide a gripping effect, or the wall sections can be roughened or pitted to provide a similar gripping effect. Fig. 11H shows a grasper 430 with a layer of adhesive 432 on its inner wall section. Fig. 11I similarly depicts a grasper 432 with its outer wall section 434 pitted or roughened.

An additional embodiment of a grasper 438 as shown in Fig. 11J incorporates stiffening fibers 440 along the longitudinal axis of the grasper 438 between the outer wall section 34 and inner wall section 38 of the grasper 438. For the application of torque, the fibers could be placed spirally around the longitudinal axis, or a crossed mesh of fibers could be provided. This latter embodiment could transmit torque in both directions. For applications in which additional tensional stiffness of the grasper is desired, the grasper can be made of a rubber or other elastomer with a high modulus of elasticity.

Still another embodiment of a grasper incorporates strips of a hooked fabric such as Velcro (Trademark) on its surface to improve adhesion between the grasper and the article to be grasped. Fig. 12 shows a grasper 442 with strips of Velcro (Trademark) 444 on its wall sections. The Velcro 444 extends around both the inner and outer wall sections of the grasper 442. The Velcro 444 may also be placed in larger patches on the wall sections.

Among the other applications of a manipulator according to the present invention is is use to hold a plurality of small parts such as, but clearly not limited to, screws, washers, or bolts, for sequential release at a particular location, such as onto an assembly line. Figs. 13A and 13B illustrate this application. In Fig. 13A, a grasper 446 is arranged to hold a plurality of small parts such as screws 448, which are held by the grasper 446 as the grasper 446 is revolved downwardly along the arm 450. If the small parts 448 are grasped so that they are equidistantly spaced from one another while held in the grasper 446, as shown in Fig. 13B, and a mechanism (not shown) is arranged so that the arm 450 moves downwardly relative to the grasper 446 at a constant rate of speed, the small parts 448 are released at the same position on the assembly line 452 at a constant interval of time.

This ability to hold and store objects can be put to another use by employing the manipulator as part of a launcher for grenades or other weapons. In this application, the grasper is mounted on the end of an arm to give the soldier leverage, and the grenade is released by revolving the grasper as the soldier swings the stick with sufficient force. This is akin to casting with a fishing rod.

Another application for a manipulator according to the present invention is its use with a suction apparatus to hold an object in place even though the grasper itself has been partially withdrawn from the object. This application is pictured in Fig. 14. In this application, the arm 454 is surrounded radially by a double-walled grasper 456, and the grasper 456 in turn is surrounded radially by a vacuum-tight housing 458. The housing 458 terminates in a bell-shaped flexible receptacle 460 which can be attached to a flat surface 462 to hold an object 464 in place after a partial vacuum is created by the partial withdrawal of the grasper 456 from the object 464.

Another application of the manipulator having a grasper is its use to grasp the interior of a larger object, such as, but not limited to, a box. One possible embodiment of this application is shown in Fig. 15A in which a grasper 466 is arranged radially about an arm 12; the grasper 466 is attached at its distal surface (the surface furthest from the arm) to the interior surface of a larger object such as a box 468. This application of the manipulator is made possible by its flexibility of the grasper, as the distal portion of the grasper may expand radially to encompass and grasp an object larger than the grasper and larger than could be drawn up into the interior of the grasper. If the grasper is intended to be used in this mode, a relatively soft material is used for the double-walled tube.

Another possible embodiment of the manipulator is shown in Fig. 15B. In this embodiment, the grasper 466 is equipped with a valve 470 for inflating the annular space between the inner and outer wall sections of the grasper 466. When the space is inflated by means of the valve 470, the grasper 466 makes tight contact with the walls of a box 468 so that the box 468 is grasped more securely.

Fig. 16 shows an additional embodiment of a manipulator in which the grasper is provided with a valve to inflate the annular space between its outer and inner wall sections, so that additional pressure can be exerted radially on a small object held by the grasper. In this embodiment, the arm 12 is surrounded radially by the interior wall section 472 and the exterior wall section 474 of the double-walled grasper 476. The space 478 between the interior 472 and the exterior 474 wall sections is provided with a valve 480 protruding through the exterior wall section 474 so that the space 478 can be pressurized by the admission of gas through the valve 480. The gas can be, but need not be, air; it could be, for example, helium or nitrogen if the grasper is used in an environment in which the use of air is undesirable. When the grasper 476 is inflated through the valve 480, additional pressure is exerted on an object 482 held at the end of the grasper 476, which object 482, pictured as a cylinder of narrow diameter, might otherwise be too thin to be grasped securely by the grasper 476. If sufficient pressure is exerted when the grasper is inflated, the grasper could be used to crush objects held by it, such as oranges or other fruit for the production of juice. In addition, this version of the invention can be used for grasping an object from the interior. After the grasper is revolved into the interior of an article such as a box, the grasper is inflated to increase its outer diameter to the same size as the inner diameter of the article. The pressure can be controlled and varied to vary how much force is to be exerted on a fragile article held by the grasper, or to vary the inner diameter of the grasper, thereby varying the size of the article that can be held by the grasper.

An additional embodiment of he manipulator, particularly adapted for use in remote installations such as required in robotics, is pictured in Fig. 17. In this embodiment, a grasper 482 is attached to the lower portion of an arm 484. An annular element 486 is radially adjacent to the elongate arm 484 and is in slidable contact with the exterior of the arm 484; the annular element 486 has two projections 488 which project normal to the longitudinal axis of the arm 484. A frame 490 surrounding the entire aparatus forms a cylindrical chamber 492. The projections 488 divide the cylindrical chamber 492 into two subchambers, a lower subchamber 494 and an upper subchamber 496. The annular element 486 is rigidly connected by a plurality of connecting means 498 to the grasper 482 so that motion of the annular element 486 is communicated to the grasper 482. The subchambers 494 and 496 are provided with an upper inlet 500 and a lower inlet 502 for the admission of gas into the subchambers 494 and 496. If gas is admitted through upper inlet 500, the pressure in the upper subchamber 494 is increased and the annular element 486 and the grasper 482 move downwardly relative to the arm 484. If gas is admitted through lower inlet 502, the pressure in the lower subchamber 496 is increased and the annular element 486 and the grasper 482 move upwardly relative to the arm 484. The manipulator of the present invention has an advantage over robotic manipulators utilizing rigid arms, because the grasper can flex and realign with the object to be picked up. Therefore, it can reach objects that are not centrally located.

Still an additional embodiment of a manipulator is illustrated in Fig. 18. In this alternative embodiment, the wall sections of the grasper 504 are covered by a soft, absorbent material 506 such as cotton or other absorbent fabric. In Fig. 18, the absorbent material 506 is pictured on the outer wall section of the grasper 504 but is also located on the inner wall section of the grasper 504. This embodiment of the manipulator is particularly adapted for the removal and disposal of noxious substances such as animal waste, or of liquids.

Among the other articles that can be grasped with a manipulator according to the present invention are dangerous animals, objects on the ocean floor, and dangerous articles such as radioactive pellets. The manipulator is particularly useful for changing overhead light bulbs that are difficult to reach and can normally only be reached by means of a ladder.

The basic concept of the grasper can be adapted to a nearly unlimited variety of uses. For example, a spring-loaded grasper can serve as a trap for animals which would be caught in the grasper. Also, the manipulator need not be circular and can be of various shapes. A grasper can be used to grab a formable material and in doing so shape the formable material, such as clay. If chopped meat is used as the formable material, the manipulator can serve as a sausage maker for hot dogs or other sausages.

Another application of the grasper is for turning objects inside out. If an article with a hole or other orifice is grasped by the grasper and the grasper is then pulled through the hole in the article, the article will be turned inside out or everted as the grasper is pulled through.

A system according to the present invention has significant advantages. For example, graspers having elastomeric wall sections can accommodate articles of different dimensions so that a grasper can be used to grasp elongate articles whose diameter varies along the length of the article such as, as shown in Figs. 5A, 5B and 5C, a screw.

Another advantage of the present invention is that it can be used for grasping fragile articles, such as eggs, as described above. The grasper can be used for storing and dispensing articles such as eggs. Inflating the grasper with a gas can cushion fragile articles. The grasper can be made flexible and compliant to avoid damage to the grasped article.

Another advantage of the present invention is that a single manipulator can be used for manipulating a large variety of articles. For example, with a single grasper that is expanded 6X over the arm of the manipulator, articles having diameters varying up to about 500% can be accommodated.

Although the present invention has been described in considerable detail with regard to certain preferred versions thereof, other versions are possible. For example, although the invention has been described principally with regard to the grasper being on the exterior of the arm, it is possible for the grasper to be on the interior of the arm. For example, with reference to Fig. 10, the exterior tube 370 can be considered to be the arm with the grasper 306 attached to the interior of the tube 370, while the interior tube 308 can be considered to be the activating means. In addition, an article to be grasped need not have the grasper on its exterior. For example, the article can have an opening, such as a donut, and the grasper can revolve into the opening for grabbing and manipulating the article.

Therefore the spirit and scope of the appended claims should not be limited to the description of the versions contained herein.

What is claimed is:

1. A manipulator for grasping an article comprising:

(a) an elongate arm having a forward portion;

(b) grasping means on the arm, the grasping means comprising:

i) an inner wall section which is comprised of flexible material, and

ii) an outer wall section comprised of flexible material, the wall sections forming at least a portion of a continuous, closed, double-wall structure, the inner and outer wall sections being capable of relative axial movement, the grasping means being capable of being axially revolved on the exterior of the arm so that a portion of the grasping means extends beyond the forward portion of the arm for grasping the article; and

(c) means permanently attaching a portion of the grasping means to the arm such that when the grasping means is revolved beyond the forward portion of the arm and grasps an article, it cannot be revolved off of the arm.

2. A manipulator for grasping an article comprising:

(a) an elongate arm having a forward portion; and

(b) grasping means on the exterior of the arm, the grasping means comprising:

i) an inner wall section which is comprised of flexible material, and

ii) an outer wall section comprised of flexible material, the wall sections forming at least a portion of a continuous, closed, double-wall structure, the inner and outer wall sections being capable of relative axial movement, the grasping means being capable of being axially revolved on the exterior of the arm so that a portion of the grasping means extends beyond the forward portion of the arm for grasping the article, wherein the inner circumference of the inner wall section of the installed grasper is less than the outer circumference of the arm, and wherein the unstressed inner circumference of the inner wall section of the grasping means is sufficiently less than the outer circumference of the arm that both wall sections of the grasping means exert a force toward the arm normal to the surface of the arm.

3. A manipulator for grasping an article comprising:

(a) an elongate arm having a forward portion; and

(b) grasping means on the arm, the grasping means comprising:

i) an inner wall section which is comprised of flexible material, and

ii) an outer wall section comprised of flexible material, the wall sections forming at least a portion of a continuous, closed, double-wall structure, the inner and outer wall sections being capable of relative axial movement, the grasping means being capable of being axially revolved on the exterior of the arm so that a portion of the grasping means extends beyond the forward portion of the arm for grasping the article, wherein the unstressed inner circumference of the inner wall section of the grasping means is sufficiently less than the outer circumference of the article when the grasping means is on the article that both wall sections of the grasping means exert a force toward the article normal to the surface of the article for grasping the article.

4. The manipulator of claim 1, 2 or 3 in which the grasping means is on the exterior of the arm and the ratio of the outer circumference of the arm to the inner circum-

ference of the inner wall section of the grasping means before it is placed on the arm is no more than about 5.

5. The manipulator of claim 2 in which the ratio of the outer circumference of the arm to the inner circumference of the grasping means before it is placed on the arm is no more than about 5.

6. The manipulator of claim 1, 2 or 3 in which the wall sections have an annular region therebetween.

7. The manipulator of claim 6 in which there is friction reducing means in the annular region.

8. The manipulator of claim 7 in which the friction reducing means is a lubricant.

9. The manipulator of claim 7 in which the thickness of the friction reducing means is sufficiently small that the wall sections are separated by a distance not greater than about 10 times the minimum thickness of the wall sections.

10. The manipulator of claim 1 wherein the attaching means is an adhesive between the grasping means and the arm.

11. The manipulator of claim 1 in which grasping means is on the exterior of the arm and the arm is hollow.

12. The manipulator of claim 11 in which the internal diameter of the arm is sufficiently large that once the article is grasped by the grasping means, the grasping means can be axially revolved onto the arm such that the article is deposited inside the arm.

13. The manipulator of claim 1, 2 or 3 including means for moving the arm.

14. The manipulator of claim 1 wherein the grasping means is on the exterior of the arm, the inner circumference of the inner wall section of the grasping means before it is placed on the arm is less than the outer circumference of the arm, and the unstressed inner circumference of the grasping means is sufficiently less than the outer circumference of the arm that both wall sections of the grasping means exert a force toward the arm normal to the surface of the arm.

15. The manipulator of claim 1 or 14 wherein the grasping means is on the exterior of the arm, the inner circumference of the inner wall section of the grasping means before it is placed on the arm is less than the outer circumference of the arm, and the unstressed inner circumference of the inner wall section of the grasping means is sufficiently less than the outer circumference of the article that both wall sections of he grasping means exert a force toward the article normal to the surface of the article when the grasping means is revolved onto the article.

16. The manipulator of claim 1 including activating means for remotely revolving the grasping means on the arm.

17. The manipulator of claim 16 wherein the grasping means is on the exterior of the arm and the activating means is permanently attached to a portion of the outer wall section of the grasping means.

18. The manipulator of claim 17 wherein the activating means comprises an elongated rod with a tubular element secured thereto, the tubular element being attached to the outer wall section of the grasping means.

19. The manipulator of claim 1 or 2 wherein the article has an opening therein, and the grasping means is sized to fit into the opening.

20. A tool for manipulating a movable article comprising:

(a) a handle for a human hand;

(b) an elongate arm attached to the handle, the arm being adapted for directly engaging the article; and

(c) grasping means on the arm, the grasping means comprising:

i) an inner wall section which is comprised of flexible material, and

ii) an outer wall section comprised of flexible material, the wall sections forming at least a portion of a continuous, closed, double-wall structure, the inner and outer wall sections being capable of relative axial movement, the grasping means being capable of being axially revolved on the exterior of the arm so that a portion of the grasping means extends beyond the forward portion of the arm for grasping the article.

21. The tool of claim 20 wherein the grasping means is on the exterior of the arm and the inner circumference of the inner wall section off the grasping means before it is placed on the arm is less than the outer circumference of the arm.

22. The tool of claim 21 wherein the unstressed inner circumference of the inner wall section of the grasping means is sufficiently less than the outer circumference of the article that both wall sections of the grasping means exert a force toward the article normal to the surface of the article for grasping the article when the grasping means is revolved onto the article.

23. The tool of claim 21 or 22 wherein the unstressed inner circumference of the inner wall section of the grasping means is sufficiently less than the outer circumference of the arm that both wall sections of the grasping means exert a force toward the arm normal to the surface of the arm.

24. The tool of claim 20 including means for permanently attaching a portion of the grasping means to the arm such that when the grasping means is revolved beyond the forward portion of the arm and grasps an article, it cannot be revolved off of the arm.

25. The tool of claim 21 comprising a screwdriver where the arm is the shaft of the screwdriver and the article is a screw.

26. The tool of claim 21 comprising a bolt or nut driver wherein the arm is a shaft of the driver and the article is a bolt or nut.

27. A method for moving a movable article comprising the steps of:

(a) selecting a manipulator comprising an elongate arm having a forward portion and grasping means on the exterior of the forward portion of the arm, the grasping means comprising:

i) an inner wall section which is comprised of flexible material; and

ii) an outer wall section comprised of flexible material, the wall sections forming at least a portion of a continuous, closed, double-wall structure, the inner circumference of the inner wall section of the grasping means before it is placed on the arm being less than the outer circumference of the arm so that the inner and outer wall sections are capable of relative axial movement;

(b) grasping the article by applying an axial force onto the outer wall section of the grasping means toward the article while the inner wall section of the grasping means is restrained from axial motion in that axial direction, thereby axially revolving the grasping means along the exterior of the arm beyond the forward portion of the arm and onto the article; and

(c) moving the arm, the grasping means, or both, after grasping the article for moving the grasped article.

28. The method of claim 27 wherein the manipulator includes means for permanently attaching a portion of the grasping means to the forward portion of the arm so that the grasping means cannot be revolved off of the arm.

29. The method of claim 28 wherein the attaching means is an adhesive between the grasping means and the arm.

30. The method of claim 27 or 28 where the unstressed inner circumference of the inner wall section of the grasping means is sufficiently less than the outer circumference of the article that both wall sections of the

grasping means exert a force toward the article normal to the surface of the article for grasping the article.

31. The method of claim 30 where the unstressed inner circumference of the inner wall section of the grasping means is sufficiently less than the outer circumference of the arm that both wall sections of the rasping means exert a force toward the arm normal to the surface of the arm.

32. The method of claim 27 wherein the unstressed inner circumference of the inner wall section of the grasping means is sufficiently less than the outer circumference of the arm that both wall sections of the grasping means exert a force toward the arm normal to the surface of the arm.

33. The method of claim 27 in which the step of grasping the article comprises revolving the grasping means onto the article until the article is completely enclosed by the grasping means.

34. The method of claim 27 including the additional step of releasing the grasped article by axially revolving the grasping means along the exterior of the arm away from the forward portion of the arm.

35. The method of claim 27 in which the ratio of the outer circumference of the arm to the inner circumference of the inner wall section of the grasping means before it is placed on the arm is no more than about 5.

36. The method of claim 27 in which the wall sections have an annular region therebetween.

37. The method of claim 36 in which there is friction reducing means in the annular region.

38. The method of claim 37 in which the friction reducing means is a lubricant.

39. The method of claim 37 in which the thickness of the friction reducing means is sufficiently small that the wall sections are separated by a distance not greater than about 10 times the minimum thickness of the wall sections.

40. The method of claim 27 in which the arm is hollow and the grasping means is on the exterior of the arm.

41. The method of claim 40 wherein after the article is grasped by the grasping means, axially revolving the grasping means onto the arm such that the article is deposited inside the arm.

42. The method of claim 27 wherein the manipulator is a hand tool having a handle sized for a human hand with the elongate arm attached thereto, the arm being adapted for directly engaging the article.

43. The method of claim m42 wherein the hand tool is a screwdriver with the arm being the shaft of the screwdriver and the article being a screw, the step of moving the arm

after grasping the article comprising rotating the shaft for screwing the screw into or out of a substrate.

44. The method of claim 42 wherein the hand tool is a bolt driver with the arm being the shaft of the driver and the article being a bolt, the step of moving the arm after grasping the article comprising rotating the shaft for threading the bolt into or out of a substrate.

45. The method of claim 42 wherein the hand tool is a nut driver with the arm being the shaft of the driver and the article being a nut, the step of moving the arm after grasping the article comprising rotating the shaft for unthreading the nut onto or off of a substrate.

46. The method of claim 27 wherein the article has an opening and the step of grasping comprises revolving the grasping means into the opening.

47. A method for placing an article into a cavity comprising the steps of:

(a) selecting an applicator comprising:

i) an elongate arm having a forward portion, and a forward end adapted for pushing on the article,

ii) holding means on the exterior of the forward portion of the arm, the holding means comprising an inner wall section comprised of flexible material and an outer wall section also comprised of flexible material, the wall sections forming at least a portion of a continuous, closed, double-wall structure, the inner and outer wall sections being capable of relative axial movement, and

iii) means for permanently attaching a portion of the holding means to the arm so that the holding means cannot be revolved off of the arm;

(b) placing the article inside the holding means with the holding means revolved beyond the forward end of the arm;

(c) placing a forward portion of the holding means into the cavity; and

(d) pushing the arm forwardly toward the opening, thereby revolving the holding means onto the arm for depositing the article into the cavity.

48. The method of claim 47 wherein after the article is deposited in the cavity, the additional step of pulling the arm away from the opening, thereby revolving the holding means off of the arm.

49. The method of claim 48 in which the arm is pulled away from the opening until the holding means is also pulled from the opening.

50. The method of claim 47 in which the cavity is an animal orifice.

51. The method of claim 47 in which the step of placing a forward portion of the holding means into the cavity comprises revolving a portion of the holding means into the cavity.

52. The method of claim 47 in which the step of placing a forward portion of the holding means into the cavity comprises sliding a portion of the holding means into the cavity.

53. The manipulator of claim 1, 2 or 3 in which at least one of the wall sections of the grasping means is provided with supplementary means to assist in grasping an article.

54. The manipulator of claim 54 in which the supplementary means comprises a plurality of projections projecting in a direction transverse to the longitudinal axis of the manipulator from at least one of the wall sections.

55. The manipulator of claim 53 in which the supplementary means comprises a plurality of ridges arranged circumferentially around at least one of the wall sections.

56. The manipulator of claim 53 in which the supplementary means comprises a plurality of ridges arranged longitudinally along at least one of the wall sections.

57. The manipulator of claim 54 in which the projections are in a staggered arrangement.

58. The manipulator of claim 53 in which the supplementary means comprises a plurality of ridges on at least one of the wall sections, the ridges being aligned at an acute angle to the longitudinal axis of the grasping means.

59. The manipulator of claim 53 in which the supplementary means is an adhesive means.

60. The manipulator of claim 53 in which the supplementary means is a hooked fabric.

61. The manipulator of claim 1, 2 or 3 in which the surface of at least one of the wall sections is roughened whereby grasping of the article to be held by the grasping means is made more secure against relative motion of the article and the grasping means.

62. The manipulator of claim 1, 2 or 3 in which the grasping means is provided with an absorbent means on at least one of its wall sections.

63. The manipulator of claim 6 in which the annular region is provided with inflating means.

64. The manipulator of claim 16 wherein the activating means comprises means for automatically reciprocatingly revolving the grasper backwards and forwards on the arm.

65. An apparatus for holding an article in place by suction comprising:

(a) an elongate arm having a forward portion;

(b) grasping means on the arm, the grasping means comprising:

i) an inner wall section which is comprised of flexible material, and

ii) an outer wall section comprised of flexible material, the wall sections forming at least a portion of a continuous, closed, double-wall structure, the inner and outer wall sections being capable of relative axial movement, the grasping means being capable of being axially revolved on the exterior of the arm so that a portion of the grasping means extends beyond the forward portion of the arm for grasping the article;

(c) means permanently attaching a portion of the grasping means to the arm such that when the grasping means is revolved beyond the forward portion of the arm and grasps an article, it cannot be revolved off of the arm; and

(d) a flexible bell-shaped housing surrounding the grasping means which is capable of retaining a vacuum created when the grasping means is first revolved forward to grasp the article and then revolved backward slightly away from the article.

66. The method of claim 36 in which the grasped article is held more securely after grasping by inflating the annular region with a gas.

67. The method of claim 66 wherein the grasped article is crushed by the inflation of the grasping means between its inner and outer walls after the article is grasped.

68. The method of claim 42 wherein the hand tool is a torque wrench with the arm being the shaft of the torque wrench and the article being an object upon which torque must be exerted, the step of moving the article after grasping the article comprising rotating the shaft for applying torque for installing or removing the object, without the arm contacting the article.

69. A method for holding an article in place by suction comprising the steps of:

(a) selecting a manipulator comprising an elongate arm having a forward portion, grasping means on the arm, the grasping means comprising:

i) an inner wall section which is comprised of flexible material, and

ii) an outer wall section comprised of flexible material, the wall sections forming at least a portion of a continuous, closed, double-wall structure, the inner and outer wall sections being capable of relative axial movement, the grasping means being capable of being axially revolved on the exterior of the arm so that a portion of the grasping means extends beyond the forward portion of the arm for grasping the article, means permanently attaching a portion of the grasping means to the arm such that when the grasping means is revolved beyond the forward portion of the arm it cannot be revolved completely off the arm, and a flexible bell-shaped housing surrounding the grasping means which is capable of retaining a partial vacuum created when the grasping means is revolved forward to grasp the article and then revolved backward slightly away from the article;

(b) placing the manipulator over the article to be held; and

(c) revolving the grasping means forward to grasp the article; and

(d) revolving the grasping means backward and away from the article to create suction on the article.

70. A method for molding a formable article comprising the steps of:

(a) selecting a manipulator comprising an elongate arm having a forward portion and grasping means on the exterior of the forward portion of the arm, the grasping means comprising:

i) an inner wall section which is comprised of flexible material, and

ii) an outer wall section comprised of flexible material, the wall sections forming at least a portion of a continuous, closed, double-wall structure, the double-wall structure having a cross-section corresponding to the design to be molded, the inner circumference of the inner wall section of the grasping means before it is placed on the arm being less than the outer circumference of the arm so that the inner and outer wall sections are capable of relative axial movement;

(b) grasping the formable material by applying an axial force onto the outer wall section of the grasping means while the inner wall section of the grasping means is restrained from axial motion in that axial direction, thereby axially revolving the grasping means along the exterior of the arm beyond the forward portion of the arm and onto the formable material;

(c) allowing the formable material to harden in the grasping means to a consistency such that the grasping means may be released from the formable material without disturbing the shape into which the formable material has been molded; and

(d) revolving the grasping means upward axially along the arm to release the molded formable material from the grasping means.

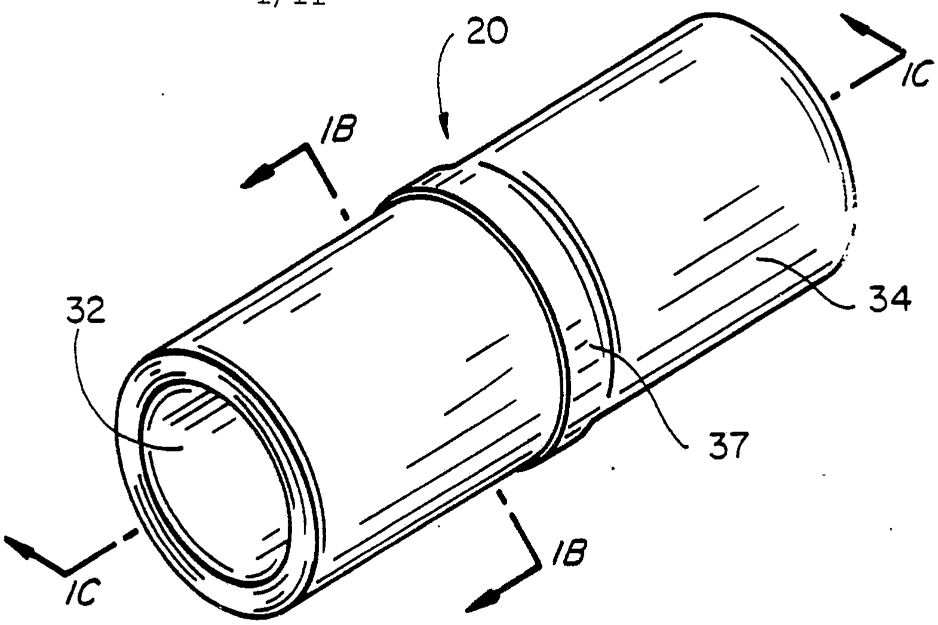

FIG_1A

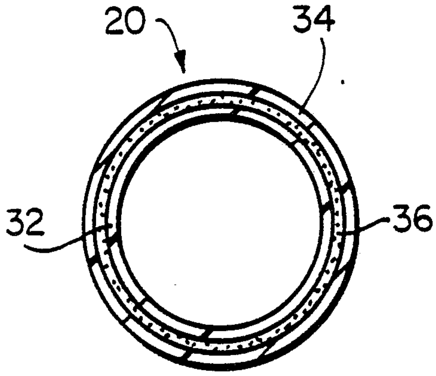

FIG_1B

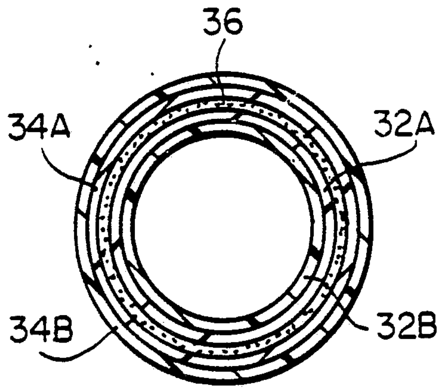

FIG_1D

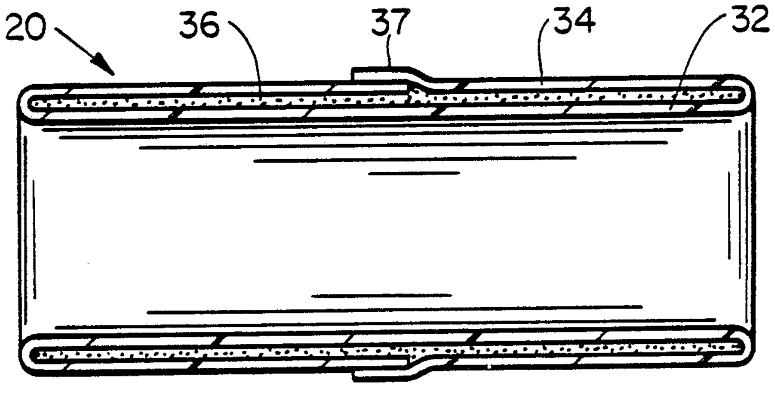

FIG_1C

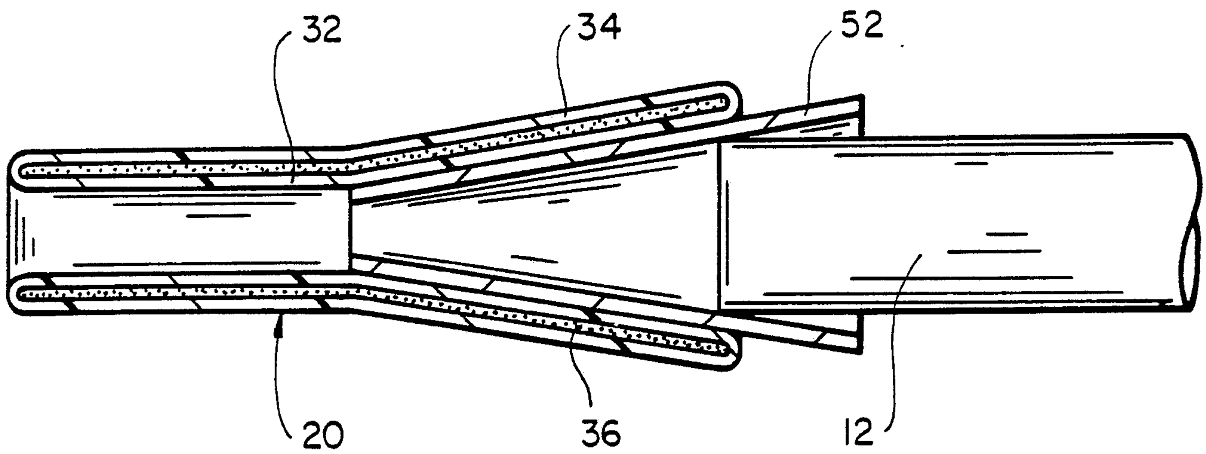

FIG_2

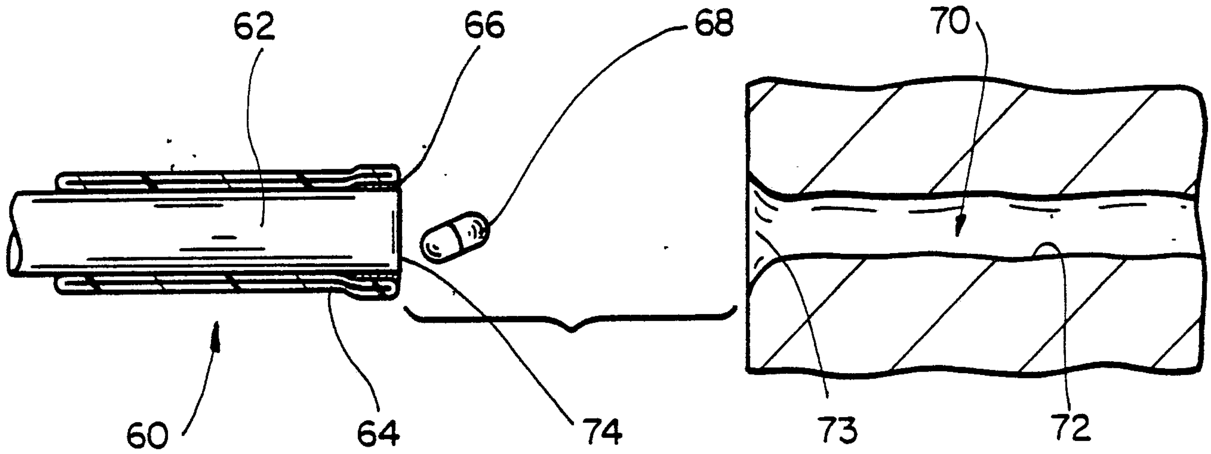

FIG_4A

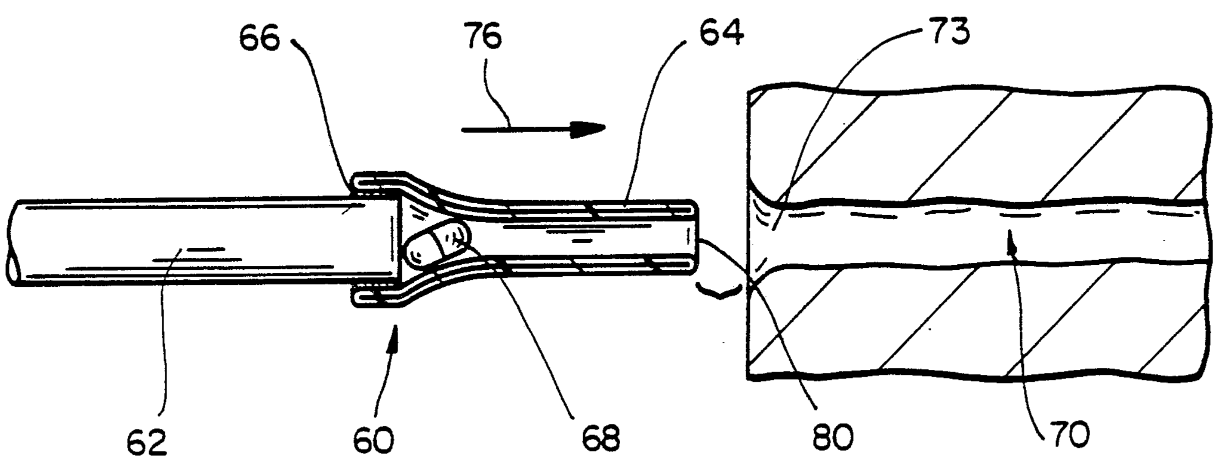

FIG_4B

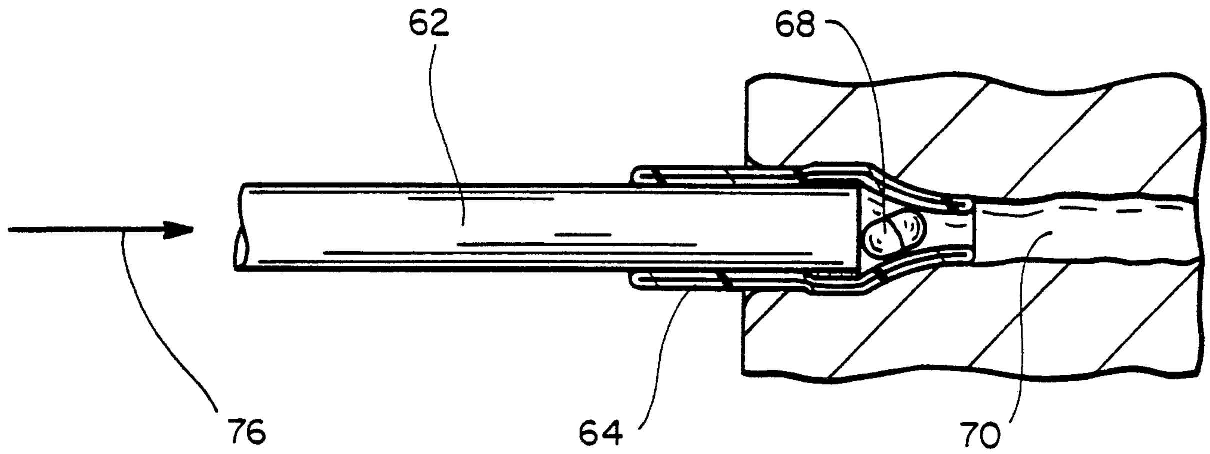

FIG_4C

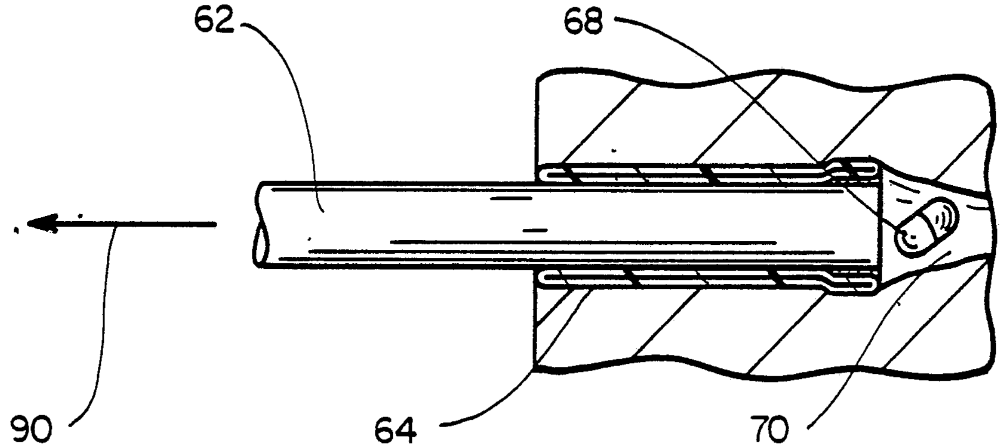

FIG_4D

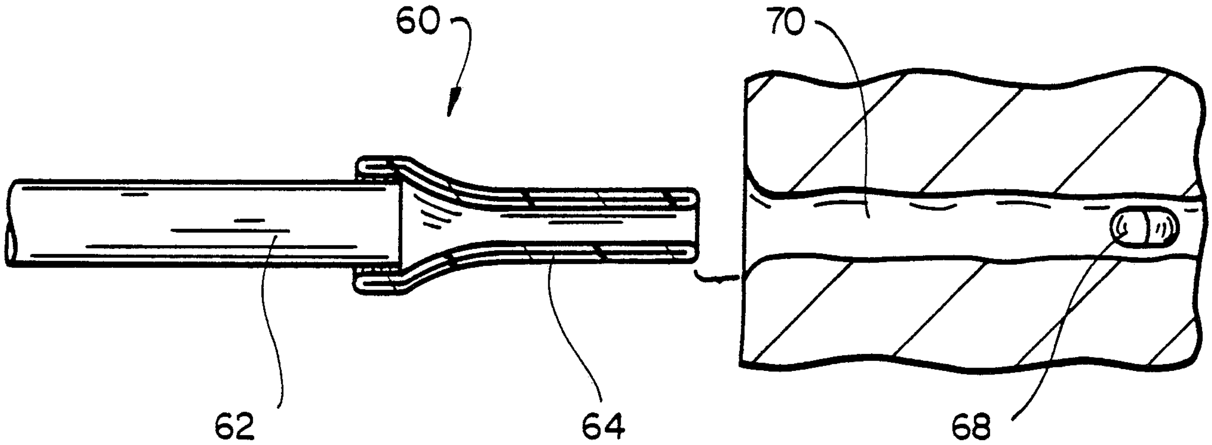

FIG_4E

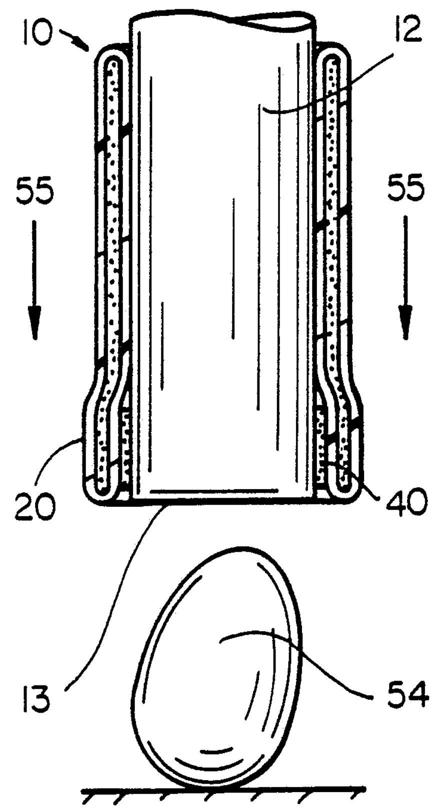

FIG_3A

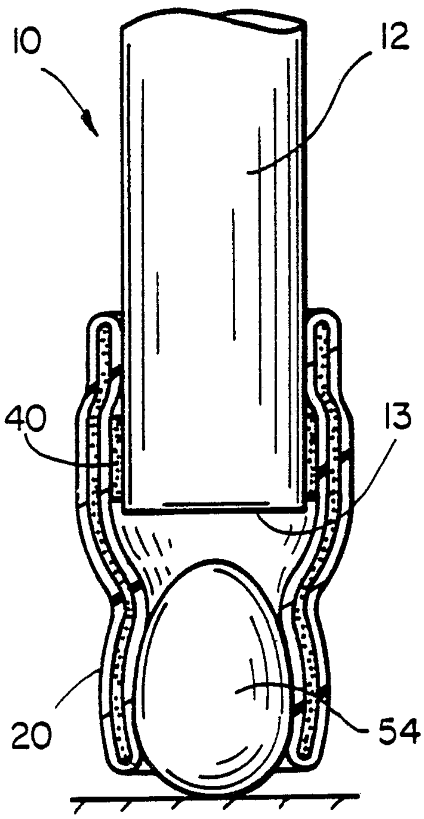

FIG_3B

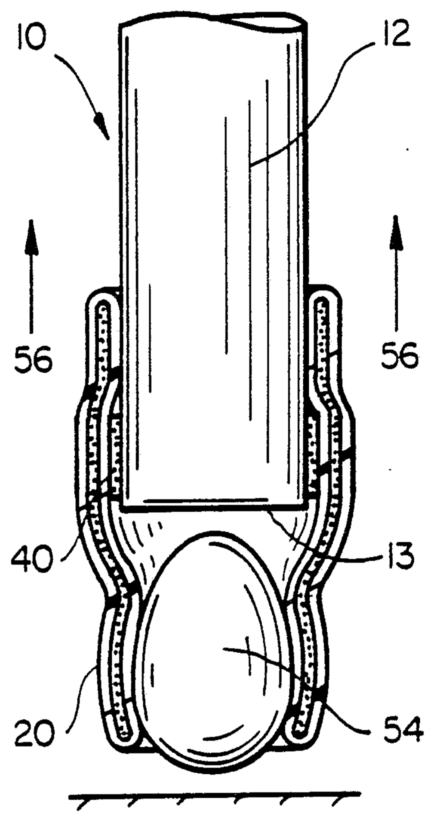

FIG_3C

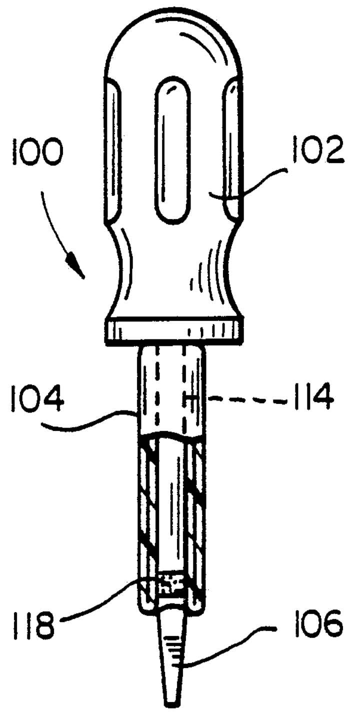

FIG_5A

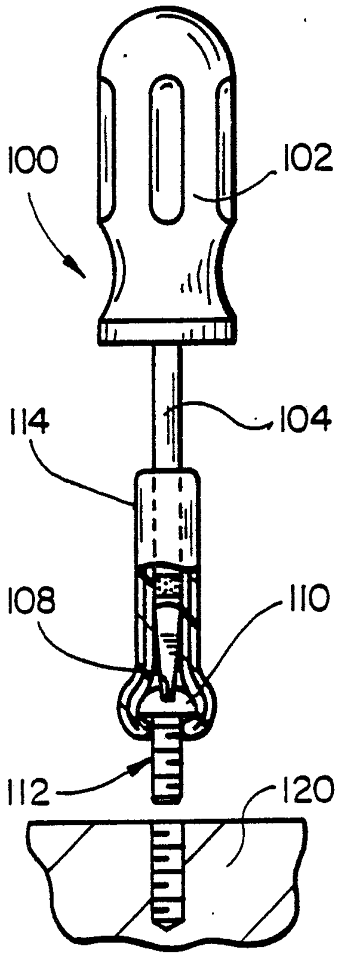

FIG_5B

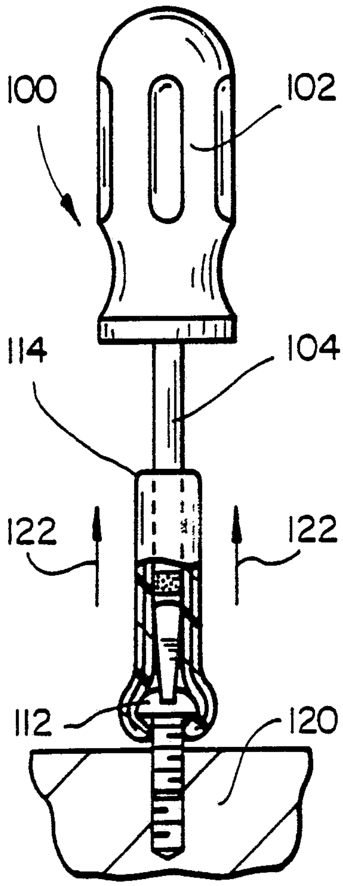

FIG_5C

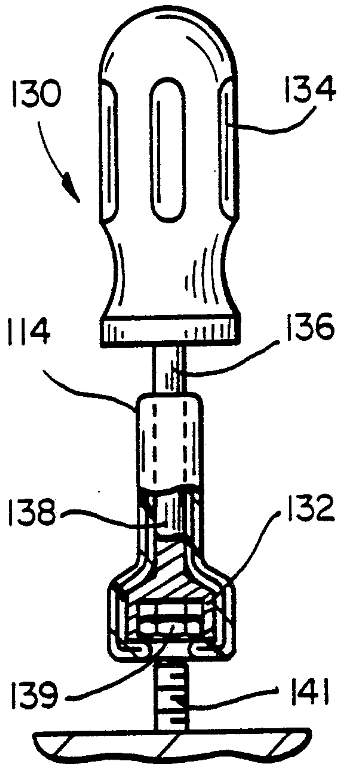

FIG_6

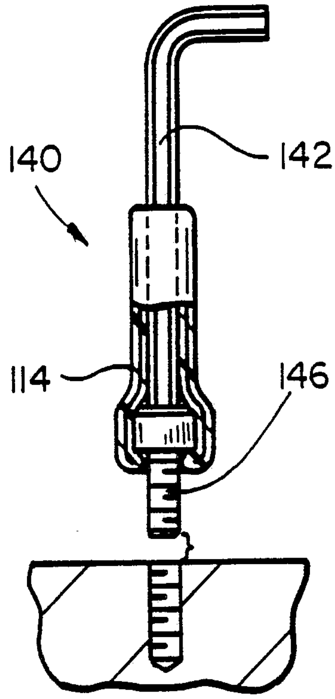

FIG_7

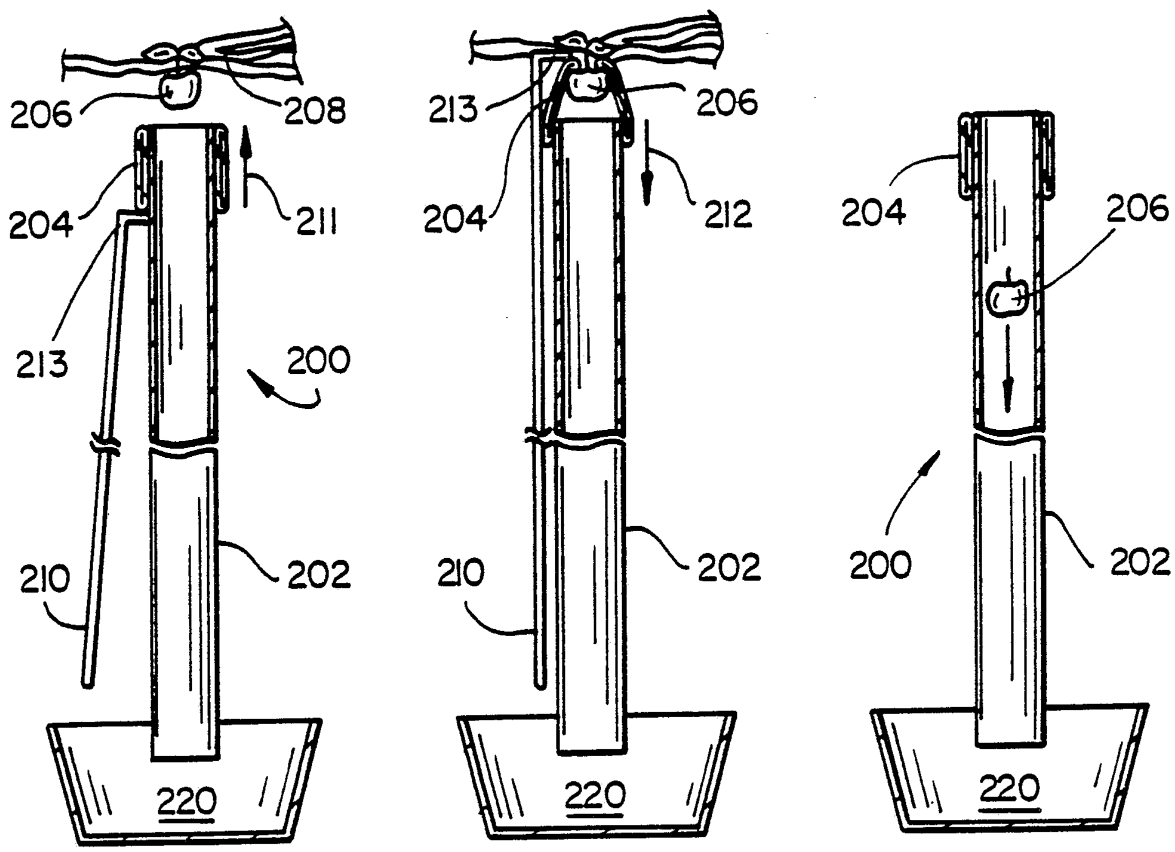

FIG_8A FIG_8B FIG_8C

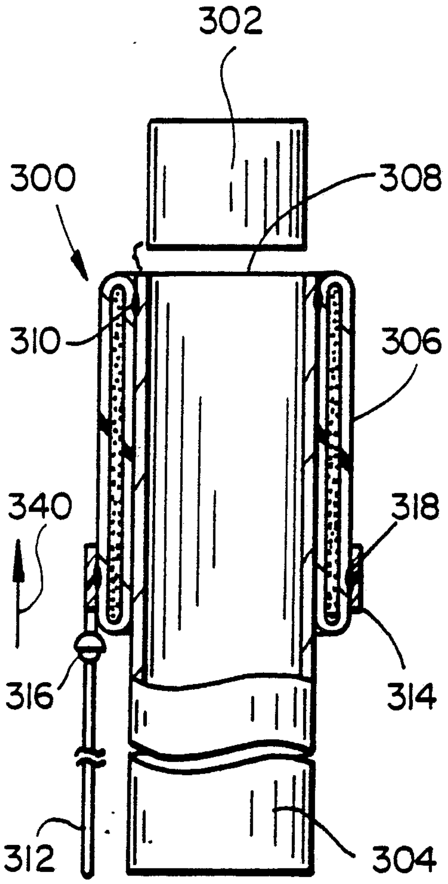

FIG_9A

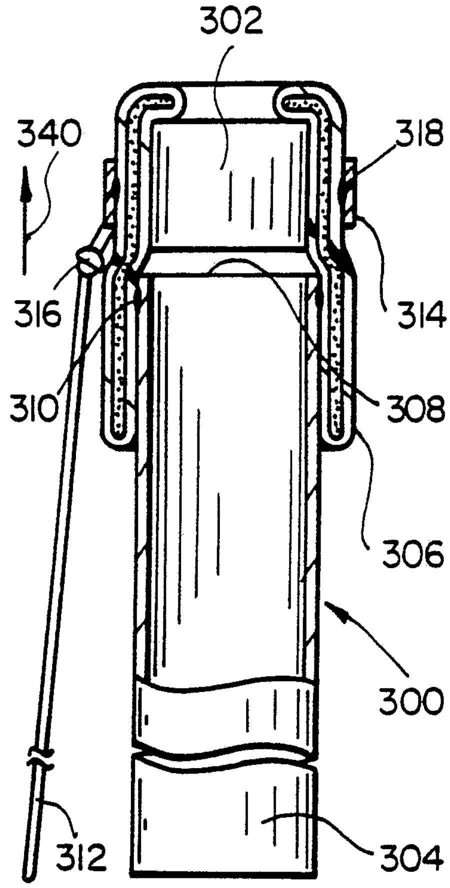

FIG_9B

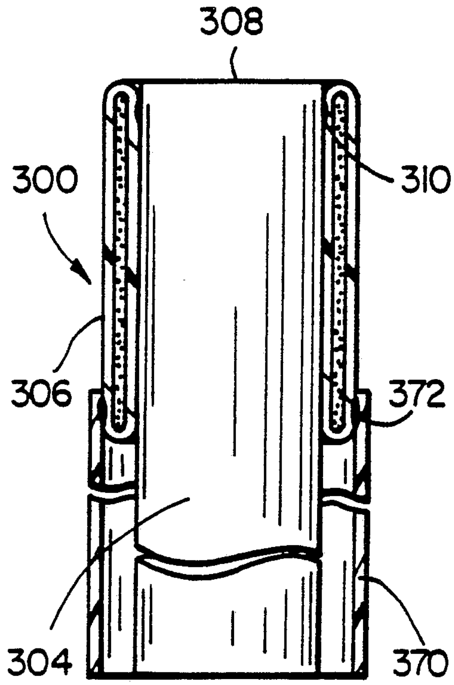

FIG_10

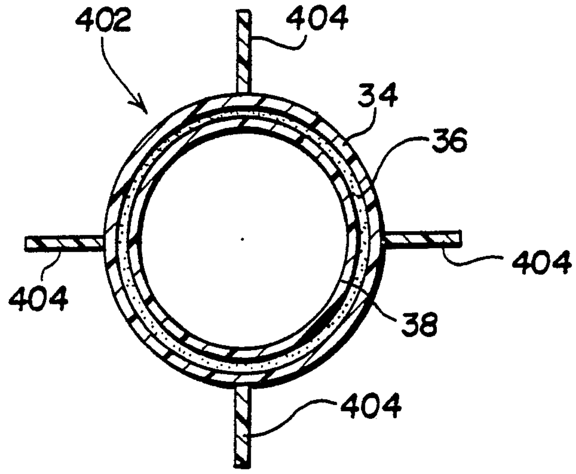

FIG. 11A

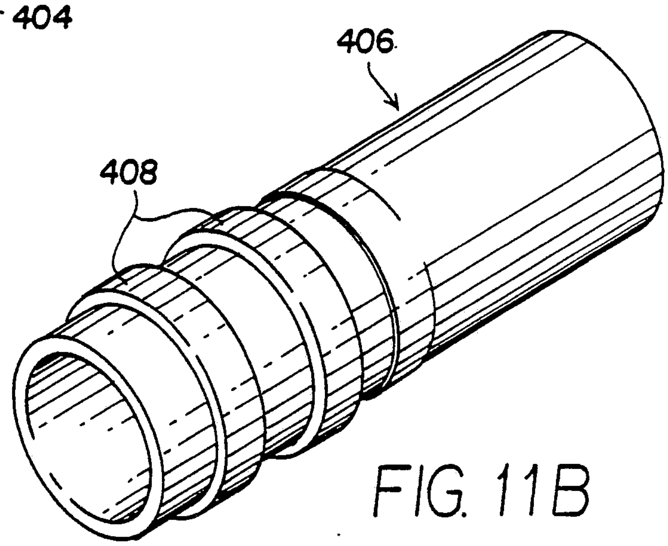

FIG. 11B

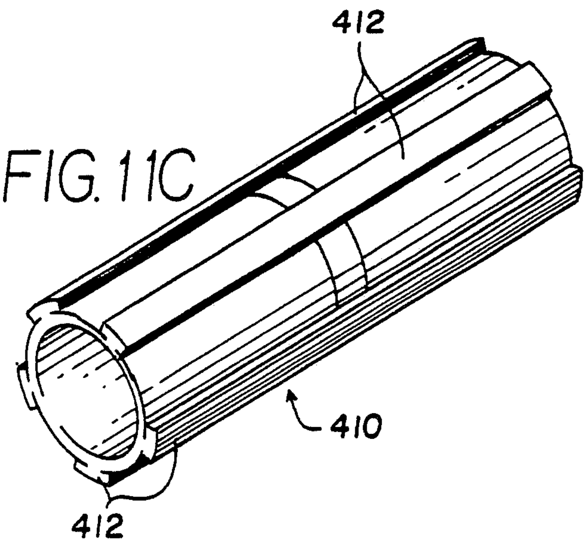

FIG. 11C

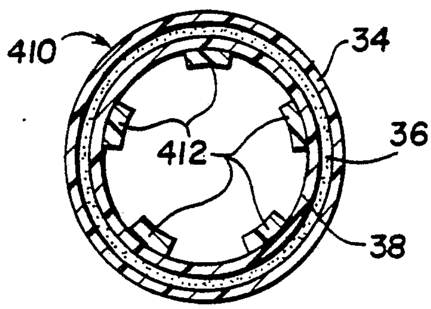

FIG. 11D

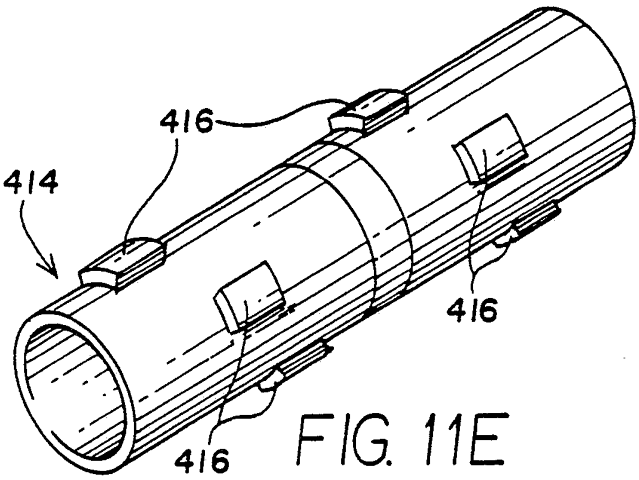

FIG. 11E

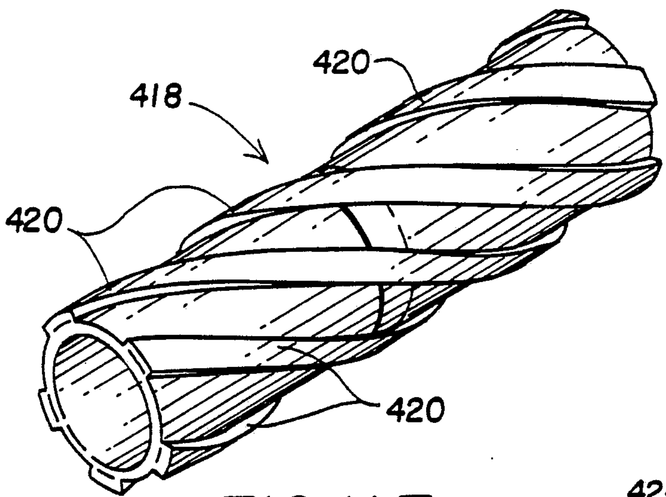

FIG. 11F

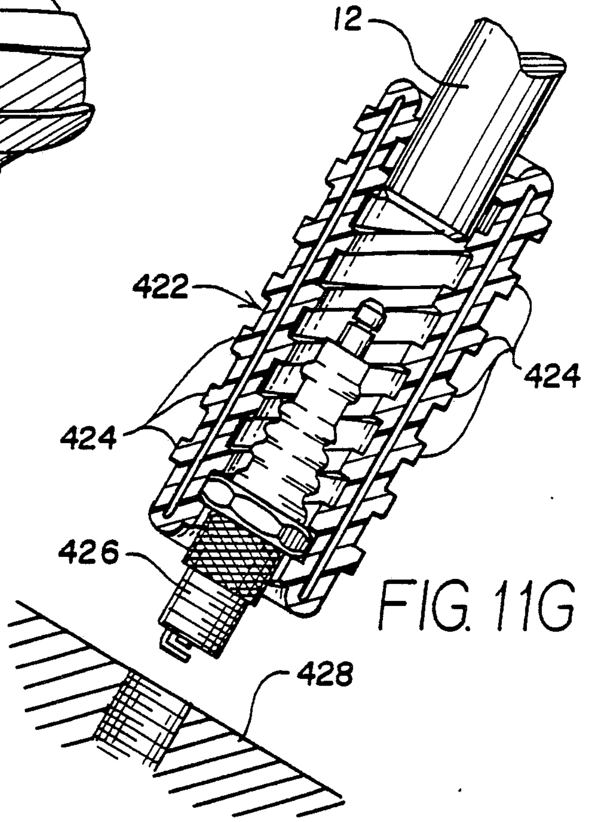

FIG. 11G

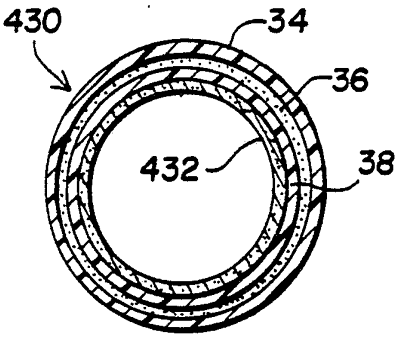

FIG. 11H

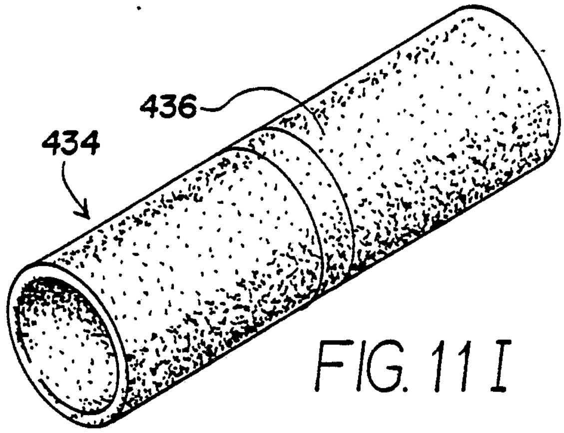

FIG. 11I

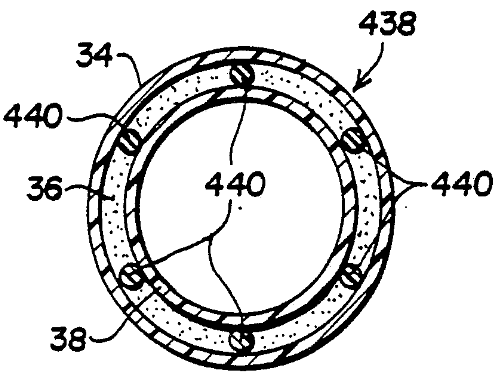

FIG. 11J

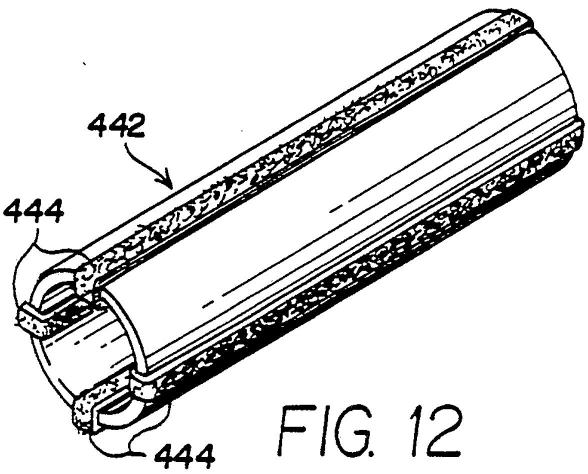

FIG. 12

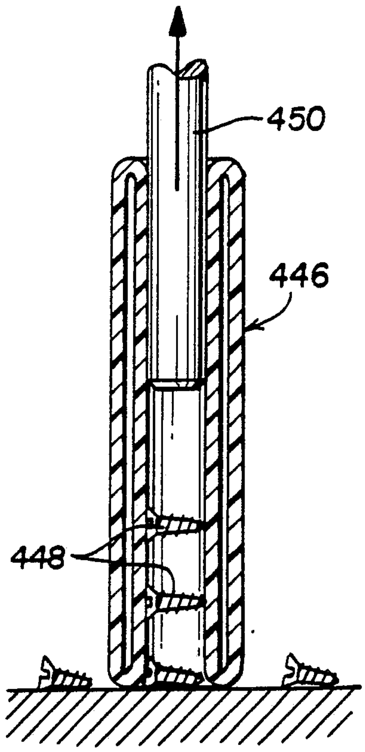

FIG. 13A

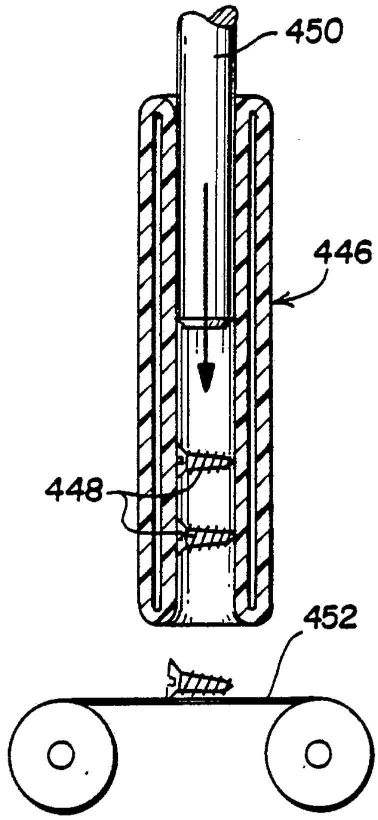

FIG. 13B

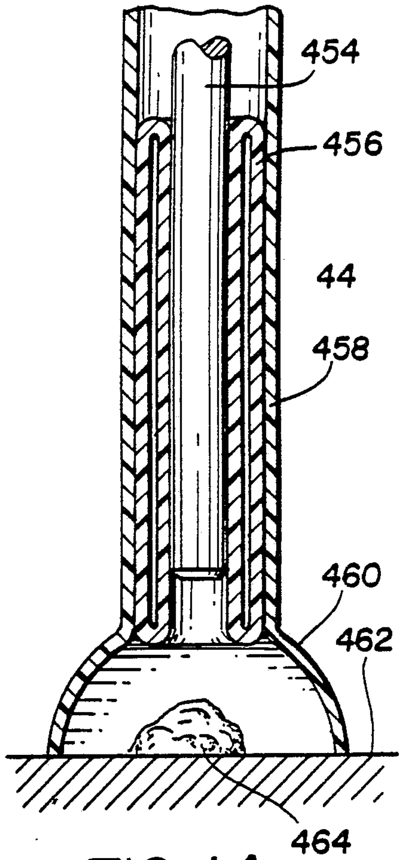

FIG. 14

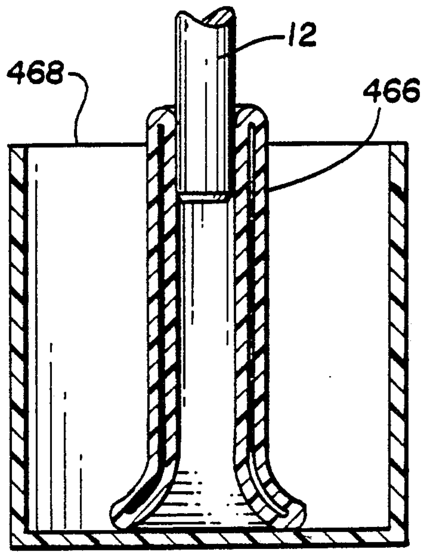

FIG. 15A

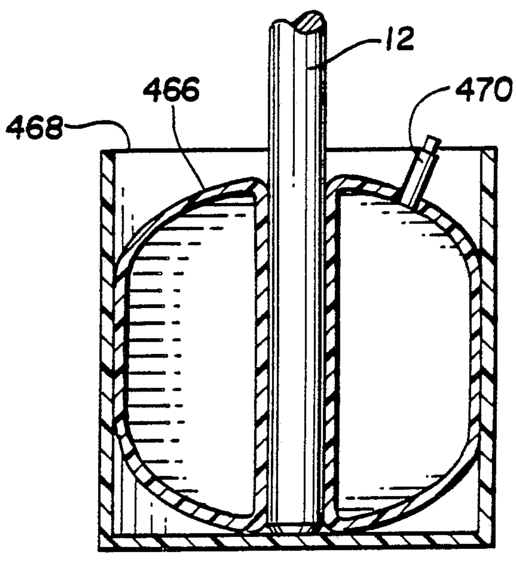

FIG. 15B

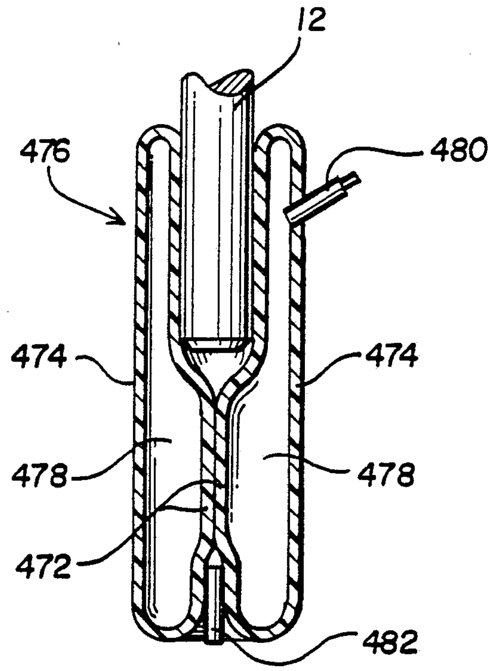

FIG. 16

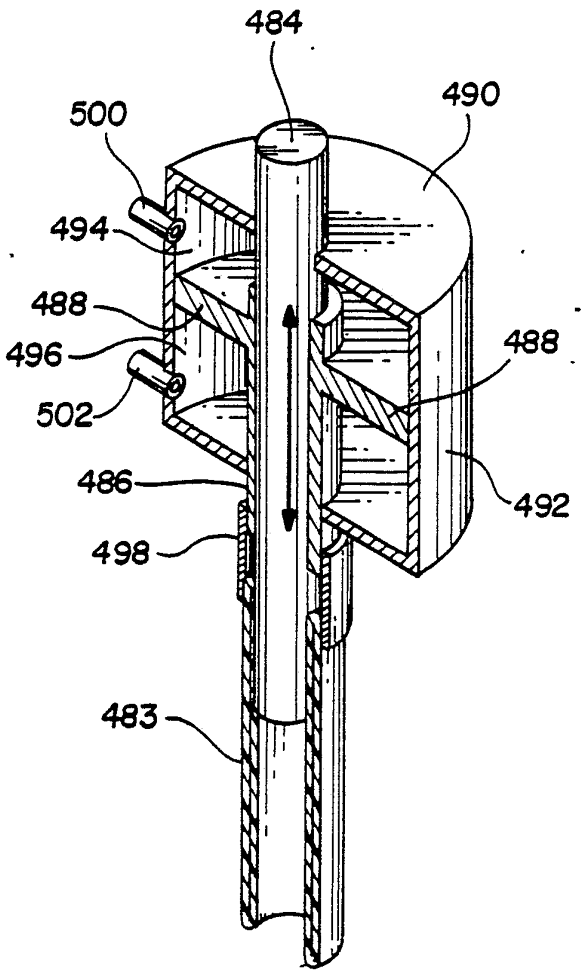

FIG. 17

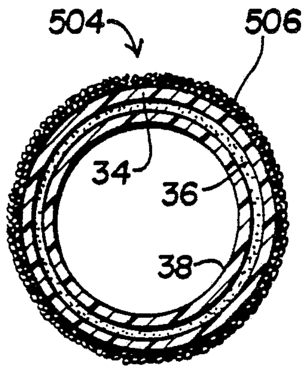

FIG. 18

INTERNATIONAL SEARCH REPORT

International Application No PCT/US87/02336

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC (4): B25B 11/00; B65G 7/12
U.S. Cl. 294/99.1; 294/15

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
U.S.	294/99.1, 15, 1.1; 81/13, 44, 451, 452, 458; 128/1.2 604/11, 14, 16, 18, 904, Dig. 1; 206/582, 328

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
Y	US, A, 3,284,123 (Adams) 08 November 1966. See the entire document.	1-6,10-36, 40-46,53-70
Y	US, A, 2,763,507 (Haley) 18 September 1956. See the entire document.	1-6,10-36, 40-46,53-70
Y	US, A, 3,404,822 (Green) 08 October 1968. See column 2, lines 17-35.	10,29,30,31
Y	US, A, 3,322,007 (Cunningham) 30 May 1967. See column 1, lines 37-51.	11,12,14,15, 17,18,20-26, 40-42
Y	US, A, 3,245,466 (Morifuji) 12 April 1966. See column 2, lines 10-22.	25,43
Y	US, A, 3,707,894 (Stillwagon, Jr.) 02 January 1973. See column 2, lines 27-43.	26,44,45
X	US, A, 4,496,341 (Brucks) 29 January 1985. See entire document.	47-52

* Special categories of cited documents: [15]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
06 January 1988	26 JAN 1988
International Searching Authority [1]	Signature of Authorized Officer [20]
ISA/US	James B. Marbert James B. Marbert

Form PCT/ISA/210 (second sheet) (October 1981)